The

ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XX No. 9 SEPTEMBER, 1959

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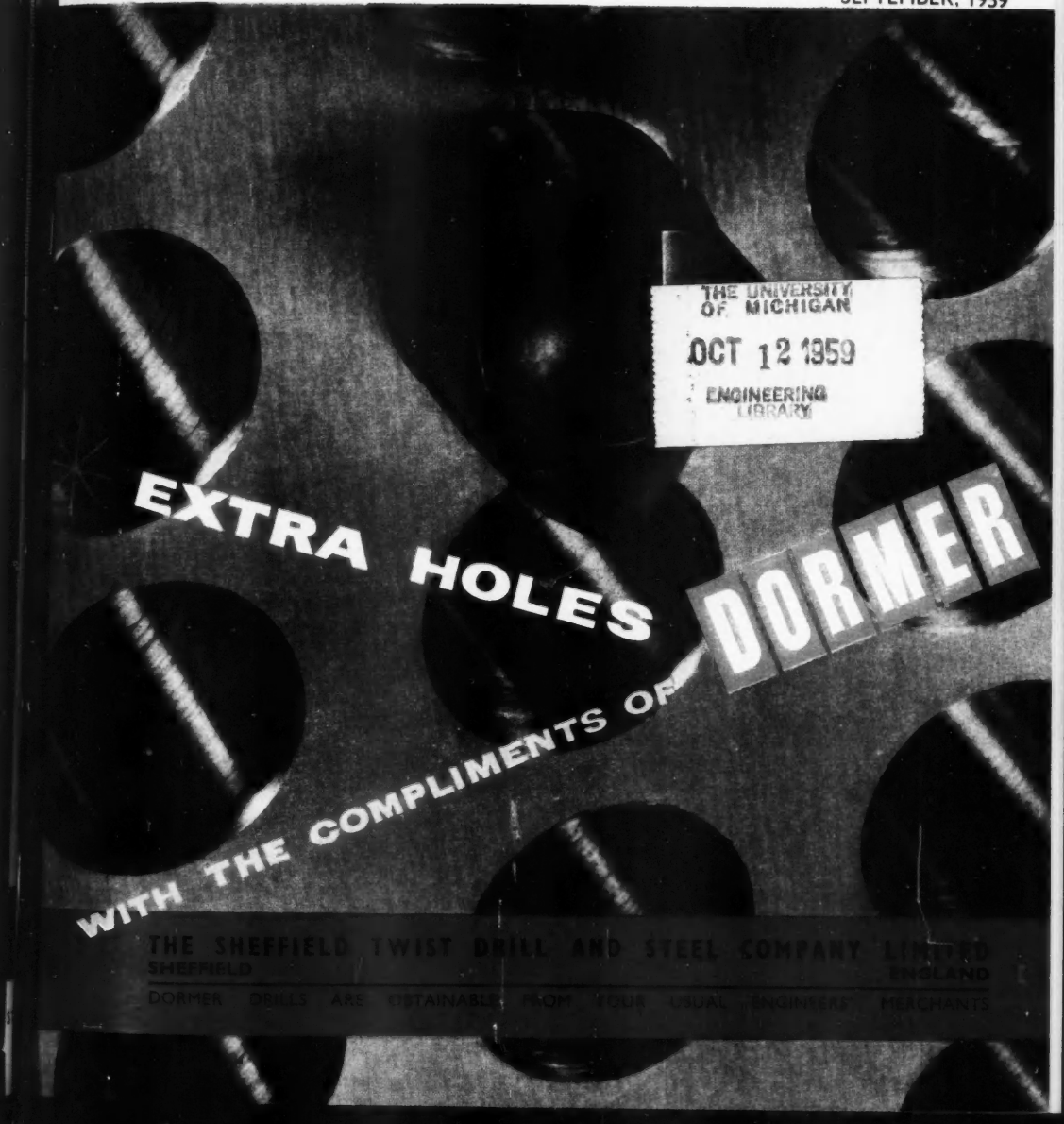

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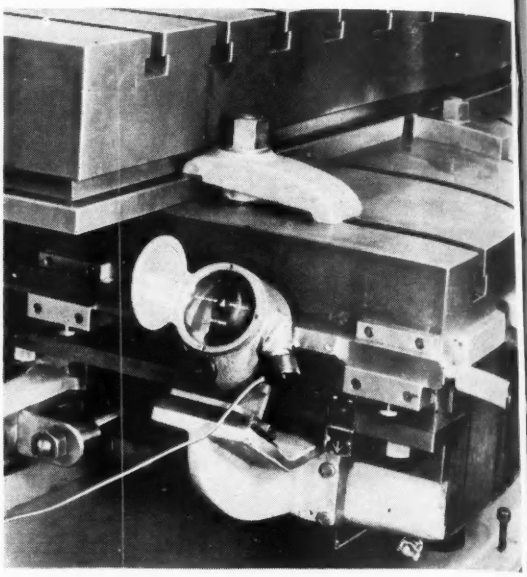

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THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

• *CONTROL OF THICKNESS OF COLD-ROLLED STEEL STRIP*

In view of the fact that consumers of cold-rolled steel strip are laying increased emphasis on the uniformity of gauge from one side of the strip to the other, an interesting method of meeting this requirement has been developed, in which use is made of radiant gas burners spaced across the top roll of a cold-finishing mill, so as to heat and expand the roll, thereby ensuring uniform thickness of the strip. It has been found that satisfactory control of strip thickness has been achieved by the quick response of the burners used, in which combustion is confined to a refractory cup, so that the gas flames do not actually touch the roll. The use of such ceramic burner surfaces which become incandescent and emit radiant heat to the surface of the mill roll, is important, inasmuch as absence of flame impingement is required to prevent the deposition of soot on the strip. A combustion controller feeds a mixture of gas and air to the burner tip, and this mixture is distributed radially, burning against the cup-shaped refractory surface. Heating time is kept to a minimum, owing to the controlled rate of heat transfer and the short distance between the roll surface and the burners. In one particular installation, nine radiant heater units are spread across the top roll at a distance of 3 to 4 in., and the thickness of the steel strip is carefully measured as it passes through the mill. As soon as uneven thickness is detected, the burners are ignited, where necessary, to expand low spots on the roll. It is stated that the strip can thus be held to within 0·0002 in. of nominal thickness and that wrinkling is prevented.

• *MODIFIED PLASMA JET AS A SPECTROSCOPIC SOURCE*

A modified plasma jet, developed to serve as a spectroscopic source, and producing temperatures up to 8000°C, offers promise as a means of excitation for the spectrographic analysis of complex alloys. The plasma-jet concept involves heating a gas stream to extremely high temperatures by constricting an electric arc passing between two electrodes, with the hot ionized gas comprising the arc plasma emerging through an opening in the cathode as a flame-like jet. For spectrochemical analysis, a solution of the test specimen is drawn through a capillary tube and is sprayed into the arc plasma, the plamsa jet vaporizing the solution and exciting the elements to emit spectra which would not ordinarily be obtained with the lower temperatures of chemical flames. In fact, the temperature of 8000°C obtained with a direct current of from 15 to 20 A is sufficient to excite all elements in solution. In this plasma-jet device, an argon-operated atomizer is held within a co-axial water-cooled chamber and is protected by a graphite cap which serves as the anode. Inside the atomizer is a stainless-steel hypodermic needle, through which the test solutions flow to the atomizer tip. At one end, the atomizer and the anode are enclosed in a hard-rubber cylindrical case, while a graphite disc with a central opening is held by a water-cooled brass ring at the other end, this disc serving as the cathode. It is interesting to note that the high temperature produced by the plasma jet is due to the thermal " pinch " effect, heat from the direct-current arc being concentrated into a narrow region between the electrodes by helium gas, which acts as a " coolant ", introduced tangentially into the rubber case. The temperature of the plasma is highest at the cathode, decreasing as the hot gas expands and radiating energy.

• *IMPROVED VACUUM ARC-MELTING PROCESS*

The increasing use of metals with high melting points, such as titanium, zirconium, tantalum, and tungsten, has led to notable developments in connection with arc-melting techniques, which are usually carried out in a vacuum or in inert gases, usually at pressures between 10 and 100 mm Hg, so as to prevent reaction of the metal with nitrogen, oxygen, or hydrogen. Arc-melting techniques, however, have given rise to a number of problems, not the least of which is the fact that the metals in question contain in their raw condition appreciable quantities of gas in a dissolved or occluded form, or absorbed into their surface, this gas being liable to be released after heating in the electric arc. According to a recently patented method of arc-melting, however, it is claimed that it is possible to eliminate in advance any gases which have hitherto been set free during melting and which have caused splashing and interference with the operation of electric-arc equipment. In particular, this improved method is intended to provide powerful degasification, so that a substantially greater quantity of gas can be eliminated than is possible

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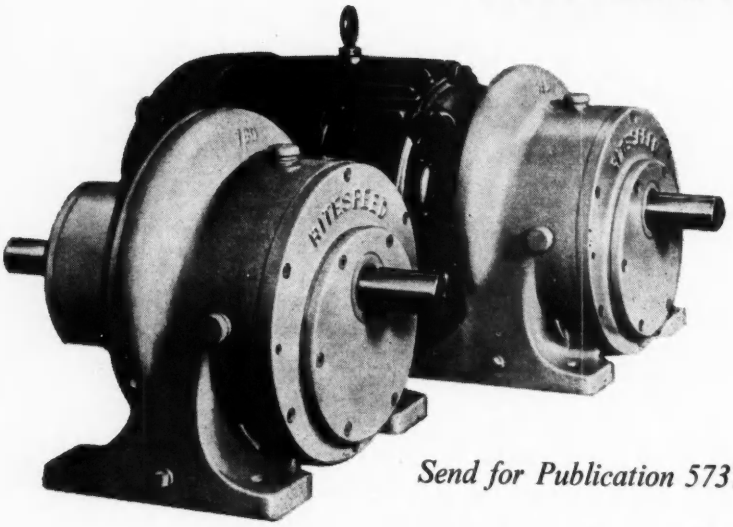

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by gettering, for instance. In addition, the method prevents any quantities of gas expelled from combining again in any form with the melted and solidifying metal, thereby contributing to its increased purity. Basically, the method comprises providing the metal to be melted in a non-coherent metallic form, progressively forming a firm rod-shaped electrode from the non-coherent material, and then feeding the electrode towards the arc zone. During its progress towards the arc zone, the electrode passes through a pressure-reduction stage, in which the gas pressure progressively decreases, thereby degasifying the electrode before it reaches the arc zone. For forming the electrode, a mechanical pressing device, capable of exercising a pressure of from 2000 to 10,000 kg/cm², is used, the electrode diameter ranging from 30 to 70 mm. In order to reduce to a minimum the adverse effects of any residual nitrogen or oxygen in the arc zone, the introduction of argon at a point in advance of the arc zone proper is recommended. Only very small quantities of argon are required, as the pressure in this stage of the pressure chamber is between 0·001 and 0·1 mm Hg. As an example of the great improvement in quality effected by this process, it is stated that tests have been carried out on melted titanium sponge, which gave a metal with a Vickers hardness of 180 kg/mm² when subjected to conventional methods of degasification, as compared with 150 to 160 kg/mm² with the new method, where preliminary degasification was effected before melting. This reduction in hardness is claimed to increase the ductility of the titanium to an extent which may well be decisive for its practical use.

● ***DETECTION OF INCIPIENT FATIGUE IN METALS BY ULTRASONICS***

Fatigue in metals can be observed by various physical means, but in most cases the procedures necessary to detect the structural changes have their own influence on the fatigue life of the metal. Also, it is rather difficult to predict from these observations the unexpended fatigue life left in the metal. Many uncertainties are caused by the fact that until now there is no detailed quantitative description of the fundamental processes which lead to fatigue failure. A recent research report, however, points out that the modern theory of dislocation may pave the way to an understanding of fatigue, and that ultrasonic wave propagation through metals is connected with energy absorption and velocity dispersion which have been linked with dislocation mechanisms. While available ultrasonic pulse techniques in the megacycle range have so far been used for the study of metals subjected to plastic strains and their recovery phenomena, they have now also been applied to the study of fatigue. As a result, it is hoped that observation of the change in attenuation and possibly velocity during the active fatigue process may afford a valuable insight into the fundamental mechanisms involved. Likewise, the study of fast recovery phenomena may prove significant in the indication of permanent fatigue damage. Furthermore, the use of surface waves may produce answers to the questions as to how the final fatigue crack develops, while scattering measurements may possibly be valuable in detecting the occurrence of fatigue centres distributed throughout the bulk of the material. The breakdown of the crystal lattice during fatigue may produce heat bursts which might result in detectable ultrasonic warning signals. Finally, it is believed that further development of recording systems, together with information storage and computing devices, may make the interpretation of complex signals possible, and thus facilitate in-service testing.

● ***FLEXIBLE CO-AXIAL CABLE FOR TEMPERATURES UP TO 1000°F***

The development is reported of a highly flexible co-axial cable which can withstand temperatures as high as 1000°F, as generated in manned supersonic and hypersonic air-breathing vehicles. Each cable is a completely sealed radio-frequency transmission system and consists of inner and outer conductors separated by a dielectric of modified semi-solid silica, and provided with a protective sealed metallic convoluted jacket. Each cable end is provided with a hermetic seal, incorporating screw threads for radio-frequency connectors. It is claimed that the electrical performance of the new cable compares favourably with that of standard co-axial cables, characteristic impedance, capacitance per foot length, and velocity ratio being the same as for cables with P.T.F.E. dielectrics; also, although attenuation rises with temperature, it remains well within practical limits up to 1000°F. Extreme flexibility is claimed to be an important feature of the new cable; thus, in flexing and endurance tests, samples were bent first through 90 deg. in one direction and then through 90 deg. in the opposite direction over mandrels of 5 in. in diameter. After 30,000 cycles the dielectric exhibited no change in physical characteristics or insulation resistance. Bending of the cable requires very little force, and bend diameter has no effect on the performance of the system.

● ***IMPROVED HOT-EXTRUSION PROCESS***

Further improvements in the well-known hot-extrusion technique using glass as a lubricant have been proposed, with special reference to materials which are difficult to extrude, e.g., high-speed steel and refractory alloys such as

Lighting - 1

Good lighting affects productivity in three ways: (1) by directly increasing the speed of working and reducing errors and wastage; (2) by improving overall factory efficiency through better supervision and housekeeping; (3) by providing better working conditions, thus improving labour relations and avoiding frequent changes of workpeople.

It is not possible to judge by the eye alone whether the lighting in any factory is good enough to serve these purposes because the eye has a tremendous range of adaptation (vision of some kind is possible within an illumination range of 1,000,000 to 1) and is hence an unreliable measuring instrument. Severe mental and eye strain or unconscious slackening of working speed may occur under lighting which *appears* to be adequate.

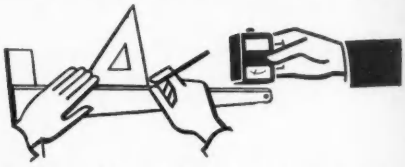
The only reliable way to appraise factory lighting is to conduct a lighting survey using a lightmeter, an inexpensive instrument which measures the actual illumination available. These figures can then be compared with official recommended values for the various tasks.

Lighting Survey

A methodically conducted lighting survey is the first step towards achieving good productive lighting. The average artificial illumination at working height should first be measured. This requires a number of readings at various positions relative to the lighting fittings, particularly beneath and between fittings and by the wall. The average of the readings should then be compared with the illumination values recommended by the Illuminating Engineering Society. The following is a general guide to illumination requirements.

NATURE OF WORK, PROCESS OR MATERIAL	ILLUMINATION LUMENS/SQ.FT.
Rough or routine work. Large detail. Medium to light material of good contrast.	7
Ordinary work usually involving workers' inspection. Medium detail and contrast.	15
Fairly critical work, fairly small detail or poor contrast.	20
Skilled work, small detail or dark material.	30
Very fine exacting work.	100

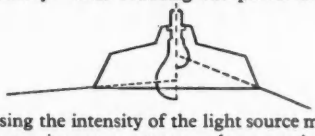
In addition, readings should be taken at selected working points with the lightmeter so placed that it measures the light on the work while the operative



is working. This will indicate whether full use is being made of the light or whether shadow is obscuring part of it.

Glare

Any direct light on the eye tends to reduce its sensitivity—thus reducing the power to see. In-



creasing the intensity of the light source may therefore not improve matters unless care is taken to avoid glare either by correct positioning or by the use of correctly matched reflectors and lamps.

Walls and Ceilings

Certain surfaces and certain colours absorb light and therefore do not make the best of a light source; others reflect light and, so to speak, feed back on to the work a portion of the lighting which would otherwise be lost. Bright walls, moreover, have a good psychological effect which makes for contented—and therefore productive—operatives.

Shadows

Unnecessary shadows may seriously slow down work and also cause accidents. Lightmeter readings should always be taken under conditions exactly similar to those obtaining while work is going on. The operative himself may mask his work, an overhead crane or a heavily loaded conveyor belt may periodically obscure a light fitting, or a dust-laden atmosphere may reduce the designed lighting values.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone: TEMple Bar 9434.

Excellent reference books are available on electricity and productivity (8/6 each or 9/- post free)—"Lighting in Industry" is an example.

E.D.A. also have available on free loan a series of films on the industrial uses of electricity. Ask for a catalogue.

7659-2

Nimonic and Stellite. When extruding these materials, it has hitherto been found necessary either to limit the rate of deformation, or to work at higher temperatures, with the consequent risk of crack formation in the product. It has been found that the viscosity of the glass and the interfacial tension between the glass and metal are of great importance, and that some metals are difficult to extrude, because a really suitable type of glass lubricant has not yet been found or may not even exist. To overcome these difficulties, it has now been proposed that the billet to be extruded should be covered with a layer of an easily extrudable metal, such as mild steel, for which a suitable glass lubricant definitely does exist. The layer can be applied in the form of a thin metal sheet, rolled and welded, or otherwise held in position, or it can be sprayed on or electro-deposited. The thickness of the layer should preferably be between 0·5 and 1·5 mm, depending on the difficulty of extrusion of the alloy concerned and on the ratio of extrusion selected. After extrusion, the layer is removed either mechanically, e.g., by machining, or chemically, e.g., by pickling. It is claimed that, with the provision of such a layer on the billet, the extrusion pressure for a given metal under identical temperature conditions is between 30 and 35% less than that required for extrusion without the layer. Furthermore, as the new method clearly creates surface conditions which are better than those obtained by conventional extrusion, it can also be applied with advantage in the case of alloys which are relatively easy to extrude, such as stainless steels.

● *MEASUREMENT OF RESISTOR NOISE*

All fixed-composition resistors exhibit noise which appears as a fluctuating voltage at the terminals, the spectral density of thermal noise depending on temperature and resistance. When direct current is passed through a granular-type resistor, an additional fluctuating voltage, called current noise, appears at the resistor terminals. The spectral density of current noise depends on the type of resistor material used, on the fabricating process, and on the structure, as well as on the size and shape, of the resistor, and, in general, is also a function of frequency. For a typical resistor, the spectral density of the current noise at 1000 cps may be 1000 times the spectral density of the thermal noise. A simple method has been developed to evaluate the noise quality of such resistors, by determining the increase in the mean fluctuating voltage at the terminals of a sample resistor when direct current is passed through it. The test set developed measures conversion gain, which is the quantity recommended for evaluating noise quality and is the ratio of available current-noise power to applied d.c. power in decibels. Conversion gain is a measure of the efficiency with which a resistor converts applied d.c. power to noise and, obviously, the more efficient is the conversion, the poorer is the noise quality. Since current noise varies inversely with frequency, measurement of conversion gain can be expected to vary in a similar manner. In testing, set noise plus current noise is measured, and current noise is computed as the difference between set noise and total noise.

● *IMPROVED METHOD OF IRRADIATING SYNTHETIC RESINS AND RUBBERS*

The use of X-rays, gamma-rays, neutrons, etc. for effecting the cross-linking or vulcanization of such synthetic resins as polyethylene and polyesters, and of natural and some synthetic rubbers, is well known. It has, however, been found that, if the radiation treatment is carried out without taking certain precautions, cross-linking may be accompanied not only by oxidation at the surface of the material, but also by oxidation within the material itself, resulting in degradation of the mass of the polymer. According to a recently patented process, these difficulties can be over come by irradiating the material in the substantially complete absence of molecular oxygen, both in contact with the surface of the material or within it. It is stated that this can be achieved by subjecting the material to degassing prior to the irradiation treatment, either in a vacuum or in an atmosphere of nitrogen, carbon dioxide, or a rare gas. A particularly convenient method is to enclose the material in an envelope which is permeable to radiation but impermeable to oxygen, e.g., aluminium foil or cellophane may be used. Another method is simply to varnish the material. In the case of polyethylene treated with gamma rays, it has been found that, in tension tests under identical conditions, the material ruptured at 184°C when treated in accordance with the new process, as compared with a temperature of 118°C when irradiated in the conventional way, i.e., in the presence of oxygen.

● *REMOVAL OF FUMES FROM GASES*

In industrial processes involving large amounts of fume-laden gas, efficient fume removal is a difficult and costly problem. This is particularly the case where the fumes are of submicron particle size, such as those consisting predominantly of iron oxide evolved in steelmaking and during the refining of molten iron

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.

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M 204 B	4 / S	72— 126	750—1200	5 1/2	8 1/4	789.0	2715
OM 636	4 / S	17— 35	1500—3000	2 15/16	3 15/16	107.8	495
OM 312	6 / S	47— 77	1500—2400	3 9/16	4 3/4	279.5	990
OM 321	6 / S	55— 94	1500—2600	3 3/4	4 3/4	311.2	1025
OM 315	6 / S	80— 124	1200—1800	4 7/16	5 1/2	505.0	1875
OM 326	6 / S	97— 155	1200—1800	5 3/64	5 1/2	660.0	1720
MB 846 A	6 / S	114— 250	750—1500	5 7/16	7 1/2	1230.2	3860
MB 846 B	6 / L	114— 250	750—1500	5 7/16	7 1/2	1230.2	3970
MB 846 Ab[1]	6 / S	148— 320	750—1500	5 7/16	7 1/2	1230.2	4080
MB 846 Bb[1]	6 / L	148— 320	750—1500	5 7/16	7 1/2	1230.2	4200
MB 846 Ad[2]	6 / S	148— 320	750—1500	5 7/16	7 1/2	1230.2	4200
MB 836 B	6 / S	230— 350	1000—1500	6 7/16	8 1/16	1806.3	4380
MB 836 Bb[1]	6 / S	305— 500	1000—1500	6 7/16	8 1/16	1806.3	4830
MB 836 Db[2]	6 / S	370— 650	1000—1500	6 7/16	8 1/16	1806.3	5050
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MB 839 Bb[2]	16 / SV	1380—2350	1000—1500	7 1/2	9 1/16	6380	11450
MB 518 [1]	20 / SV	3000	1720	7 5/16	9 13/16	8201.5	10550

S = vertical; L = horizontal; V = vee type; [1] = supercharged; [2] = supercharged and with boost intercooling
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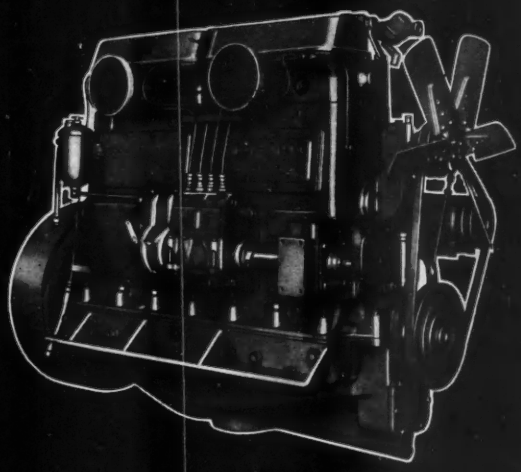

MERCEDES-BENZ DIESEL

by treatment with oxygen or oxygen-containing gases. Methods at present in general use employ equipment such as cyclones and scrubbers, which have a limited efficiency in the case of submicron-particle fumes; alternatively, electrostatic precipitators or bag filters are used, for which the installation and operating costs are high. It would therefore be desirable if the particles could be agglomerated so that such conventional equipment as cyclones and scrubbers could efficiently be used. According to a new method, the particle size can be increased by exposing the fume-laden gas to electromagnetic radiation from a radioactive source, preferably an artificial isotope, shielded from direct contact with the fume-laden gas. The electromagnetic radiation may be primary radiation such as gamma-radiation, or it may be secondary radiations resulting from electron capture, the radiation being absorbed selectively by the fume particles, with the result that an electric charge appears on the surface of the particles. The presence of fume particles charged in this manner assists agglomeration and results in an increase in the average particle size of the fumes. Although this electromagnetic radiation produces lower ionization than that obtainable from alpha-particles, the ionization is not distributed at random but is concentrated in the fume particles. Where iron oxide is, present in the fume, an isotope of iron (Fe^{55}) emitting K-radiation, is said to be a suitable radiation source.

• *IMPROVED METHOD OF GROWING METAL SINGLE CRYSTALS*

During one phase of a recent investigation concerned with basic corrosion resistance, metal single crystals were required with a definite atomic arrangement, either in their surfaces or in certain crystallographic directions in one specimen, and difficulties were experienced in producing these specimens, as they had to combine a preselected preferred orientation with the desired cross-sectional shape. Now, it is true that a preferred crystallographic orientation can be obtained by growing crystals in a horizontal furnace, but that specimens with a particular shape, e.g., cylindrical, can be produced only in a vertical furnace. In this connection, however, efforts to produce this preferred orientation in a vertical furnace have usually not been successful in the past, owing to the difficulty inherent in attaching and partially melting the seed in an upright position. To overcome this difficulty, special equipment has now been designed and consists of two cylindrical graphite crucibles, so machined that they can be joined together to hold the main crystal and the seed respectively. A cooling device is attached to the lower portion of the seed crucible to conduct heat away from the bottom of the seed and thus to prevent this portion from melting. A graphite rod, inserted in a cavity in the lower portion of the seed crucible, holds the seed in position against the bottom of the main crystal, and the assembly is lowered through the top of a vertical furnace to a position where only the upper part of the seed is melted. It has been found that seeds melted in this manner can be used over and over again. With this procedure the solidifying metal not only assumes the orientation of the original seed, but, in addition, it freezes into any desired shape.

• *HIGH-SPEED ELECTRONIC TRANSLATOR AND PRINTER*

High-speed electronic equipment has been devised which translates and prints computer output at the rate of up to 20,000 letters, numbers, and symbols per second. This equipment can read and translate binary pulses directly from a computer, magnetic tape, paper tape, or punched cards and, as an alternative to printing, the translation can be displayed on a television screen. The apparatus embodies a special cathode-ray tube, called an electrostatic printing tube, in which the conventional phosphor-faced screen is replaced by a matrix of spaced, small-diameter wires fused into its face-plate across its major dimension, the inner ends being directed towards the electron gun and the outer ends exposed to the atmosphere. In operation, an electrostatic image is first created on the printing medium, which is usually paper, by means of an electron beam which is energized and strikes the inner ends of the wires, so that it conducts electrons through the vacuum wall. These electrons are thus deposited on the paper surface, directly under the point of impingement of the electron beams, as a negative-charge pattern. To transform the electrostatic image into a visual image, the paper, which traverses the face-plate in a direction generally perpendicular to that of the wire array, is passed through a mixture of a carrier, usually negatively charged, and a toner powder, statically charged to a positive potential. The positively charged toner is attracted by, and adheres to, the negative-charge pattern imprinted on the paper by the electron beam, and the charge is fixed by applying heat, which sets the toner and produces a permanent black image.

For a further selection of items, please see our "Minidigest" section on pages A2 and A4.

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REVIEW OF WORLD ENGINEERING PROGRESS
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Possible Approaches to Controlled Thermonuclear Fusion

By R. G. MILLS, H. C. HOY, C. C. DAMM, and J. A. PHILLIPS. (From *Mechanical Engineering, U.S.A.*, Vol. 81, No. 8, August 1959, pp. 52–60, 20 illustrations)

This report summarizes four papers by different authors dealing with schemes utilizing various machines which may eventually lead to harnessing the energy of fusion. These papers respectively cover the "Stellarator" approach (R. G. Mills), the DCX machine (H. C. Hoy), the thermonuclear experiments at the Lawrence Radiation Laboratory (C. C. Damm), and the Los Alamos Programme (J. A Phillips).

THE central problem in a controlled thermonuclear reaction is the confinement of one of these isotopes at temperatures of about 100,000,000° K for useful times. A successful thermonuclear reactor must confine the plasma for about a second or longer. This requirement can be met either on an intermittent basis by holding each pulse of heated plasma for a second or more, or in a continuously operating device by keeping each new particle in the plasma for that time. This required time of containment could be shortened if the magnetic-field strength could be raised much above the value of 100,000 gauss. Unfortunately, there are limitations on the electric current that magnet coils can stand, and these have tended to limit progress in this direction.

There are many paths of approach to obtaining a confined hot plasma. Some start with a cold gas in a containing magnetic field and then heat the gas by electrical discharges, as well as by "magnetic squeezing". Others utilize the electrical discharge to produce both heat and the confining magnetic field (pinch devices). Still others start with individual ions made energetic in an accelerating device and then trapped in a magnetic field, either by rapidly raising the field strength or by the break-up of a larger ion group (i.e., a molecule) by an electric arc. Some details of these schemes are given in the following papers.

THE "STELLARATOR" APPROACH

The "Stellarator" is envisaged as a continuously operating (as opposed to a pulsed) device, which would serve as a source of heat for a conventional steam-turbine power plant. The energy would be released by the fusion reaction produced in deuterium gas or a deuterium-tritium mixture heated to a temperature in excess of 100,000,000° K. The gas would be confined at this high temperature and kept out of contact with the physical walls of the confining tube by means of a longitudinal magnetic field produced by current in a surrounding coil. At the temperature indicated, the gas would be completely ionized, and each individual charged particle of the gas (or plasma) would be constrained by electromagnetic forces to move in a helix about a line of the magnetic field.

In this situation, assuming a stable quiescent plasma—a very difficult thing to achieve in practice—a particle will cross the magnetic field at an extremely slow rate only by being bounced from one magnetic line to a neighbouring line by a collision with another particle. On the other hand, particles are free to move very rapidly along the lines of force, so that it is necessary to block the end losses either by a method such as the magnetic mirror, which is under investigation at the Lawrence Radiation Laboratory, as described later, or to make the system endless by bending it into a closed system.

The simplest way of doing this is to close it into a torus. Unfortunately, no equilibrium confinement is possible in such an arrangement, because the field inside a torus is necessarily stronger on the inside of the bend than on the outside. This makes the radius of a particle's trajectory smaller on the inside, and particles will migrate across the field. The devastating result is that positive particles go in one direction, negative particles in the other, and there is then a crossed electric and magnetic field which produces a rapid sweep of all the particles to the wall.

The first method devised to overcome this difficulty was to twist the torus into a figure-8. This results in opposite charge separation in the other end, and electron currents along the lines of force flow to keep the field zero. This is really a diamagnetic effect of the plasma, and such a solution is a particular example of a more general principle, i.e., that of the rotational transform. Equilibrium confinement is possible through rotational transform if a closed magnetic field is constructed in any manner which results in the magnetic lines returning to any cross-section of the field in new positions rotated through an angle from the old. If the lines are not rotated—for example, if they tend to close on each other, as in the torus—equilibrium confinement is not possible. Later developments have shown that methods other than the figure-8 can be used to produce a rotational transform.

Stability:—

There are at least two types of instabilities, i.e., those that are hydromagnetic in nature, and those that are electric in nature. Hydromagnetic instabilities comprise those types of motion in which the magnetic field and its confined particles move together into a distorted shape, whereas electric instabilities are those in which electric fields are generated which drive the particles across the lines of force. Hydromagnetic instability is now well understood, but electric instability is not.

Stabilizing fields possessing the property of shear have been produced by applying currents through long-pitch helical conductors mounted just outside the vacuum tube. This stabilizing winding also produces a rotational transform, so that the figure-8 shape is not necessary in late-model Stellarators.

Heating:—

A plasma is a good conductor of electricity, and one method of heating it, called ohmic heating, is to produce an electric field in the direction of the confining magnetic field. This accelerates the electrons and, by means of collision, they impart energy to the ions.

There is an important limitation to this method of heating. The heating current must always remain below a certain upper limit. At this limit, the interaction of the field produced by the heating current and the main confining field leads to plasma instability. Furthermore, plasma has the interesting characteristic that the higher is its temperature the less is its resistance. This means that the usable heating rate gets lower and lower as the temperature is increased, and, at about 1,000,000°K, this method ceases to be helpful.

In one method of continuing to heat above this level, a modulation of the field, called magnetic pumping, produces an alternating compression and expansion of the plasma. Since the process is not completely reversible, a net heating is expected.

Impurity Control:—

A major cooling effect on any plasma is the energy lost by radiation, this radiation coming from the collision of rapidly moving electrons with the positive nuclei present in the plasma. The rate of radiation increases with the square of the atomic number of the struck nucleus, so that it is extremely important to keep impurities (most of which will come from the walls and be of high atomic number) out of the discharge. One step is to make use of ultra-high vacuum techniques which can lower base pressures to nearly 10^{-10} mm Hg but, no matter how good the vacuum or the cleanliness of the container may be, the vacuum-tube material must always be there.

To avoid contamination by wall-material atoms, use can be made of a diverter, which serves to peel off a thin outer shell of plasma where such impurities enter the field. This portion of the plasma is transported to an external chamber, where it strikes a barrier, is neutralized, and pumped out.

Experimental Results:—

From these experiments, the theoretical prediction that, at a definite value of ohmic-heating current, a sharp onset of instability would appear has been verified. Unfortunately, the most-hoped-for result, i.e., that confinement times would be long, has not been achieved. Confinement times are less than 1 millisecond, at least during the time that ohmic heating is present, and seem relatively insensitive to field strength. After the heating period is over, plasma density remains for appreciably long times (20 to 30 millisec), but these plasmas are cool. Apparently, ohmic heating leads to an instability which is not yet understood. Stabilizing windings have been added, and experiments are continuing.

Heating is also being actively studied, although the difficulties just mentioned restrict the time during which the more effective heating methods for high temperatures can be operated. Temperatures of 1,000,000 or 2,000,000°K have been achieved by ohmic heating. Furthermore, strong loading of the oscillator by the plasma at the cyclotron resonance point encourages the hope of effective heating to high temperatures by this method in the near future.

The objectives of the present experimental programme are to eliminate the instabilities which are apparently associated with the ohmic-heating process and then to apply magnetic pumping to achieve thermonuclear temperatures.

Power Generation:—

A thermonuclear power plant, based on a Stellarator type of machine, would probably be a large device generating 1000 MW or more and operating with a confining field of at least 50,000 gauss. It would very likely burn a mixture of deuterium and tritium and make use of a lithium blanket to absorb the neutron energy and regenerate tritium. The blanket would not necessarily be lithium metal, but might consist of lithium-bearing compounds or slurries of such compounds. The lithium blanket would be cooled by steam generators, the steam being used to drive conventional steam-electric plant.

The DCX Machine

Of the several machines in the U.S.A. designed to produce a controlled fusion reaction, only the DCX (Direct Current Experiment) machine developed at the Oak Ridge National Laboratory operates in a steady state.

The machine is a vacuum tank containing a magnetic field, into which a beam of energetic deuterium ions (D_2^+) is injected, and then dissociated by a new type of carbon arc. The resulting deuterons (D^+) are trapped in the magnetic field. It is hoped that by this method a large density of energetic deuterons can be obtained. As these impart energy to and ionize the neutral gas particles, a randomized plasma will be formed. If the average temperature becomes sufficiently high, thermonuclear reactions will take place in large numbers.

The unique feature of the DCX machine is the method by which energetic deuterium ions are trapped and contained. An unusual carbon-arc discharge which runs in a high vacuum causes the D_2^+ ions to dissociate either into two deuterons and an electron, or into a deuteron and a neutral deuterium atom.

If the point of dissociation is properly located, the path of the trapped particles will be a circle about the magnetic axis of the machine. The deuterons will continue to circulate in this circular path, while the undissociated part of the beam and neutral particles will escape from the working volume of the machine.

In principle, dissociative trapping can be used to ignite a thermonuclear plasma in any type of machine in which the plasma can be contained. The present attempt to produce a thermonuclear plasma is being carried out in the direct-current magnetic-mirror DCX machine, which is a linear (or axial-field) device achieving containment by a bunching of its magnetic flux lines at the ends.

The vacuum system of this machine is of the dual type, with separate pumping systems for the outer tank and the inner system or liner. Each of the separate pumping systems consists of oil-diffusion pumps backed by mechanical forepumps. Moisture in the pumping system is removed by liquid-nitrogen cold traps. The inner liner is made of copper, which is baked out at 400°C for several hours, in order to obtain a static vacuum pressure of the order of 10^{-8} mm Hg.

This liner need not be very strong structurally, as the differential vacuum between inner and outer systems is very small, the pressure difference being 10^{-2} mm Hg. The inner liner and its pumping system, in order to be bakable, must have all joints welded or be made with metallic seals. This means that any experimental probe equipment must not only have metallic seals but also must be capable of withstanding 400°C in a vacuum.

The beam of energetic deuterium ions is brought from the accelerating tube into the inner vacuum region through a differentially pumped tube. The carbon arc enters and leaves the inner liner through a baffle system, which is made of graphite to withstand the heat and is electrically insulated from the liner. Insulation is necessary to make the arc stable and to prevent the arc current from flowing through the baffles to the grounded liner.

The deuterons are contained by a mirror-shaped magnetic field produced by two coils, so made and spaced that the magnetic field produced on the machine axis at the coil centre is 20,000 gauss and that at the median plane 10,000 gauss. The power density in the coils amounts to approximately 500 W/cu in. The coils are cooled by a 1200-gpm distilled-water system.

Operational Theory:—

The deuteron density which can be obtained in the circulating ring of ions is a function of the trapped-input-ion current and the rate of escape by various loss mechanisms. One is by collision of high-energy ions with the neutral particles present at start-up as residual gas in the vacuum chamber. By a process called charge exchange, the neutral particle may become a cold ion and the energetic ion a fast neutral. The fast neutral will not be restrained by the magnetic field and will be lost to the system. The cold ions will also be lost subsequently through the magnetic mirrors. Each D^+ ion will undergo about twenty ionizing collisions before it becomes lost by charge exchange. At a certain value of trapped-ion current, therefore, the rate of ionization by the incoming beam will equal or exceed the influx of neutrals into the plasma region, and the neutrals will soon disappear. This phenomenon is called " burn-out." Theoretically, once the condition of burn-out has been reached, the circulating-ion density will build up quite rapidly to a point where thermonuclear reactions will take place.

The Future of the DCX Machine:—

An increase in beam current by a factor of 15, or a corresponding improvement in vacuum, will put the DCX machine at the burn-out critical point. The present accelerator assembly has demonstrated the ability to inject more than the needed ion current but, unfortunately, with the larger beam currents, the present vacuum system is no longer capable of attaining the previous pressures. The enlarged beam currents not only cause heating and out-gassing, but present a vacuum problem as well, since steady-state operation requires that the pumping system remove the same number of neutralized particles as are injected as ions into the beam.

Recently, the Thermonuclear Experimental Division of the Oak Ridge National Laboratory received a 600-kV power supply capable of delivering much greater beam currents. The knowledge and techniques necessary for the greatly increased ion-source output made possible by this supply are available in the division. There are, however, problems of accelerator systems and target power dissipation yet to be resolved.

The limit to which present vacuum knowledge can be extended is unknown. Indications are that the attainment of a real improvement in vacuum level will require systems, pumps, and techniques which can only be foreseen dimly at the present time.

Thermonuclear Experiments at the Lawrence Radiation Laboratory

The diverse programme of thermonuclear research at the Lawrence Radiation Laboratory is composed of the work of five main groups. The work of four of these groups is mentioned briefly in the following, a more detailed description being given of their mirror-machine programme.

Various pinch arrangements are being studied by one group, with emphasis on the investigation of plasma instabilities and energy-dissipation processes. One of the most promising of these arrangements is the sheet pinch, in which a current-carrying plasma sheet is magnetically confined either in a flat or cylindrical endless configuration, called " Triax ". A rotational plasma configuration, called the homopolar, is also being studied. Here, a radial electric field and an axial magnetic field are used to set plasma in an azimuthal drift motion. The resulting rotational kinetic energy can be converted to plasma heating by viscosity or turbulent mixing. Shock heating is also being studied, whereby a sudden increase in a weak axial magnetic field is used to cause a sudden and substantial heating of the plasma. Still another pinch phenomenon is the application of an axial magnetic field in the form of an encasing sheath to create a screw or helical dynamic pinch that extends the period of stability in the plasma.

A second group is investigating the trapping of charged particles in axially symmetric systems of electric and magnetic fields—the " ion-magnetron " arrangement. A radial electric field is applied in a magnetic-mirror geometry, and an unusual discharge in deuterium at low pressure results in the production of neutrons by an incompletely understood phenomenon.

The basic conditions necessary to the achievement of large-scale thermonuclear reactions are established in the " Astron " reactor programme by the proper use of very-high-speed electrons (relativistic electrons) in the multi-million electron-volt energy range. The electron-injection method will be studied, and an electron gun of 45-A output at 600 keV has been developed for this test.

Mirror-Machine Programme:—

The mirror-machine programme is another major effort in high-temperature plasma research. The magnetic-mirror effect arises whenever a charged particle moves into a region of magnetic field where the strength of the field increases in a direction parallel to the local direction of the field lines, i.e., wherever the lines of force converge towards each other. Such regions of converging field lines tend to reflect charged particles, i.e., they are " magnetic mirrors ". Two high-field regions enclose a low-field region in a cylindrically symmetric geometry. In the region between the mirrors, the ions travel in helical (spiral) trajectories about magnetic lines of force. As the ions penetrate into the strong field region near the end, their forward motion is impeded, and the trajectory becomes practically circular as the ions are reflected from the mirrors. Ions contained in this way make many thousands of traversals, all the while gaining energy as the magnetic-field strength is increasing.

In addition to its confining action, an increasing magnetic field theoretically not only heats, but also compresses, a plasma. After a single compression, the plasma can be transferred axially to a second mirror region by suitable variation of the magnetic fields and then be further compressed with a set of small-diameter coils.

A three-stage compression experiment, utilizing such transfers, is in progress, which reaches 200,000 gauss in a tube of 3-in. diameter for the final compression. This is accomplished without requiring the solution of the

problems involved in establishing a magnetic field of such a strength in the large initial volume. It has the additional advantage of tending to " purify " the plasma by transferring it faster than the impurities diffuse along the tube. The loss of trapped ions by electron capture from residual-gas molecules is a basic problem. To ensure long average containment times, residual gas must be kept to a minimum through the employment of ultra-high-vacuum techniques.

A recent advance of some importance to the vacuum problem is the development of a high-speed, low-base-pressure getter pump. Using molybdenum as the evaporated getter material, base pressures below 10^{-10} mm Hg have been reached in the pump itself, and pumping speeds have been estimated at above 10,000 litres/sec for hydrogen.

In summary, the mirror-machine programme has demonstrated the confinement of a plasma at significant density for many milliseconds. No instabilities have been observed. Plasma compression has been measured, and the heating of the electron component has been established. Axial transfer of the plasma has been accomplished, and some limits on the adiabatic requirements have been set.

Several types of observations have been made on the plasma so established. The electron density has been observed by the use of microwave-transmission techniques. Initial densities of between 10^{10} and 10^{13} electrons/cm^3 have been measured but, because the microwave interferometer cannot follow rapidly changing densities or accurately detect the density of small plasma columns, the density cannot be determined throughout the pulsed-field cycle. Improvement of the microwave density measurements is being pursued, and the problem of determining ion-energy distribution is under attack. Mass selection and velocity analysis establish the ion-energy spectrum and impurity content of the plasma. Several analysers are under development.

A programme for construction of an energetic plasma by trapping pre-accelerated ions, leaning heavily on advances in vacuum and ion-source technology, is also under way.

The Los Alamos Programme

The programme at the Los Alamos Scientific Laboratory has been the investigation, both theoretically and experimentally, of a number of the most promising approaches that have been proposed, most of them using magnetic-field containment. The major emphasis has been on pinch machines in both the linear and toroidal shape, these devices achieving high temperatures by magnetic compression of the plasma. Other approaches being investigated at Los Alamos include the use of crossed radial-electric and axial magnetic fields (the " Ixion " machine), a rapidly rising axial magnetic field for both containment and heating (the " Scylla " machine), and the PAM plasma-acceleration machine.

Pinch Effect:—

When a high current is passed through an ionized gas or plasma, the plasma is constricted by its self-generated magnetic field, pulling the plasma away from the walls of the containing vessel, as well as heating it by adiabatic compression. The self-confinement of a high current discharge is being investigated with a linear geometry, as in the " Columbus " machine, or with a toroidal geometry, as in the " Perhapsatron " S-4 stabilized toroidal pinch machine. The voltages are equal to or less than 80 kV, and the discharge currents are equal to or less than 1 MA.

The pinched discharge developed a number of instabilities, and experimental work with conducting walls and with the inclusion of a magnetic field has shown that the pinch can be partially stabilized. Large energy leaks in the neighbourhood of 1000 mW still exist, and work continues in the hope of plugging them up. About 10^8 neutrons per discharge have been detected from these machines, and are produced by deuterons whose centre of mass has velocities of about 5×10^7 cm/sec in a preferred direction. The mechanism of neutron production is still unknown.

The " Ixion " Machine:—

Crossed radial-electric and axial magnetic fields are used to create a spinning-plasma geometry in the " Ixion" device, which utilizes an axially symmetric configuration of magnetic and electric fields produced by concentric cylindrical electrodes and an axial magnetic field in magnetic-mirror geometry. The hot gas has an angular velocity about the axis which theoretically strongly enhances the mirror confinement, and the velocities are relatively high, as is necessary in a thermonuclear reactor. With a magnetic field of 7 kilogauss and a radial electric field of 1 kV/cm, a particle energy of 30 eV is measured by the Doppler shift.

The " Scylla " Machine:—

A rapidly rising axial magnetic field which adiabatically compresses hot deuterium gas in a mirror geometry is used in the " Scylla " device, the magnetic field being produced by a specially shaped single-turn coil energized from a 100-kV, 8·7-μF capacitor bank. With magnetic fields rising to about 60 kilogauss in 1·25 microseconds, a maximum yield of 2×10^7 neutrons per discharge is observed. To date, the evidence indicates a gas temperature of about 10,000,000°K, though more data are required to substantiate this evidence.

PAM Plasma-Acceleration Machine:—

In the PAM plasma-acceleration machine, deuterium gas is accelerated to high velocities. This is effected by first admitting a burst of gas into one end of an evacuated tube, and then, before the gas has had time to move more than a short distance down the tube, ionizing it by a high-voltage one-turn shock-coil and driving it down the tube, still at a high vacuum, by a magnetic piston. With this machine, gas velocities of 5×10^6 cm/sec have been observed, with a total plasma impulse of 90 gm-cm/sec measured with a ballistic pendulum.

The main interest in this device lies in its possible application to thermonuclear studies by the collision of two fast-moving blobs of ionized gas, and as a method of transferring pure ionized gas to other machines.

Difficulties of Plasma Measurement:—

The outstanding need in controlled thermonuclear research at present is for reliable quantitative observations on confined plasma, and the shortage of these can be blamed on the extreme mobility of plasma, the variability of gas discharges, and their sensitivity at high temperatures.

At Los Alamos, the magnetic probe has unquestionably been the most effective measuring tool, yielding measurements of plasma pressure, plasma electrical conductivity, and (most recently) plasma mass. Mean temperature has also been determined, but not its much-

(*Concluded on page 362*)

Electronic Equipment for the Direct Measurement of Indicated Mean Effective Pressure

By H. H. EMSCHERMANN. (From *VDI-Zeitschrift*, Vol. 101, No. 15, May 21, 1959, pp. 589–594, 11 illustrations)

MECHANICAL devices are still extensively used for obtaining indicator diagrams from the cylinders of reciprocating machines. More recently, inductive pick-ups with bridge amplifiers have been employed to display these diagrams on an oscilloscope, so as to obtain photographic recordings. With both methods, the indicated mean effective pressure must be evaluated from the diagrams by a planimeter or by calculation. The new electronic equipment described in this article gives the numerical i.m.e.p.-value directly during measurement, either for one working cycle or as an arithmetic mean of several consecutive cycles, on the basis of pressure pick-up indications of one or several cylinders of the reciprocating machine (with pressure impulses taken consecutively from the individual cylinders).

BASIC PRINCIPLE OF THE MEASURING SYSTEM

In a plot of pressure against volume (Fig. 1), let A_i be the area representing the work done during a working cycle, A_1 be the area bounded by the upper curve defining A_i and the top and bottom dead-centre positions of

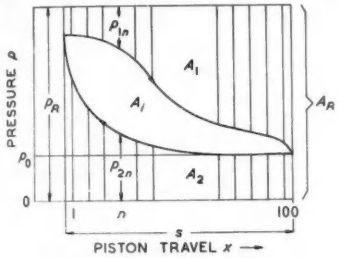

Fig. 1. **Typical indicator diagram.**

the pistons, and A_2 the area bounded by the lower curve defining A_i and the two dead-centre positions. Moreover, let A_R represent the total area of the rectangle defined by the dead-centre positions, so that $A_R = A_i + A_1 + A_2$; consequently, the mean indicated pressure is

$$p_{mi} = \frac{1}{s}\left[A_R - (A_1 + A_2)\right] \quad .. \quad (1)$$

where s is the stroke. Furthermore, if, say, 100 ordinates are used for measurements of instantaneous pressure p during the cycle, the i.m.e.p. can also be obtained as

$$p_{mi} = p_R - (B/100) \quad .. \quad (2)$$

where $p_R = A_R/s$. B represents the sum of 100 pressure values p_1 along the upper curve related to the area A_1, and of another 100 values p_2 along the lower curve related to the area A_2 in Fig. 1, the summations being carried out in opposite directions.

Now, p_R can be determined from the maximum pressure of the cycle, and a continuous sampling system can provided the p-values, which are converted electronically into corresponding "time differences" that are then totalled by an electronic counter.

For this purpose, the cylinder-pressure differences Δp are converted into voltage differences Δu_p, and the pressures p' and p'' at the starting and stopping of the sampling period are converted into voltages U_R and U_p. The conversion from $\Delta u_p = U_R - U_p$ to a time interval Δt is obtained by means of a linearly decreasing saw-tooth voltage u_s and special indicator control unit[1]. This control unit produces a starting impulse when the saw-tooth voltage u_s passes through a voltage of value U_R, and a stopping impulse when U_p is reached, as shown in Fig. 2. The time Δt elapsing between these starting and stopping impulses is proportional to Δu_p.

The Δt-values are added up by an electronic timer. The starting impulse triggers a count of oscillations occurring at a standard frequency f_n. The difficulties that have had to be overcome in practice will be appreciated to some extent, if it is noted that, to indicate seven working cycles per second, for instance, a total of 1400 time intervals Δt must be summated in one second. Moreover, the piston velocity varies non-uniformly during the stroke, so that, for each individual time interval, only a few hundred microseconds are available in the best of cases. The counter must therefore be capable of measuring microseconds.

A schematic block diagram of the electronic indicator equipment is shown in Fig. 3. The piston-position indicator (a) is driven mechanically from the piston of the reciprocating machine by means of a stroke-reducing linkage with a reduction ratio of, say, 5:1, and produces 100 impulses (e) uniformly distributed throughout the stroke, which are transmitted by a photocell (r_2) to the indicator control unit (b). The inductive pressure pick-up (c) (which can be water-cooled, if necessary) is fitted into the cylinder head and converts, with the aid of the bridge network (d), the cylinder pressure p into a proportional corresponding voltage u_p, which is also supplied through the d.c. push-pull bridge output stage to the control unit (b). When the piston-position impulse reaches the control unit (b), it triggers one starting impulse and one stopping impulse, in the manner previously outlined, starting an electronic timer (f) via a connection (g) and stopping it via a connection (h). After one working cycle, the timer indicates the numerical value B which figures in eq. (2).

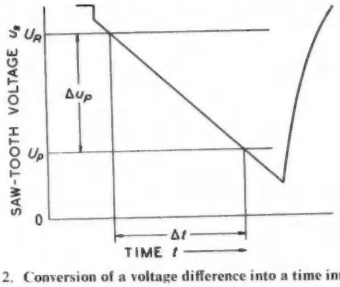

Fig. 2. **Conversion of a voltage difference into a time interval.**

The indicator control unit (b) comprises a saw-tooth generator (i) and three measuring circuits (k_R), (k_1), and (k_2), to which the saw-tooth voltage is fed simultaneously. The circuit (k_R) also has a constant reference voltage U_R applied to it, and transmits a starting impulse to the counter as soon as the saw-tooth voltage u_s reaches the value U_R. The counter (modified to provide continuous counting, instead of being reset to zero after each count) starts counting the oscillations produced by a crystal-controlled frequency standard (s) at a frequency of 1 Mcs. The circuits (k_1) and (k_2) receive the voltage u_s and also

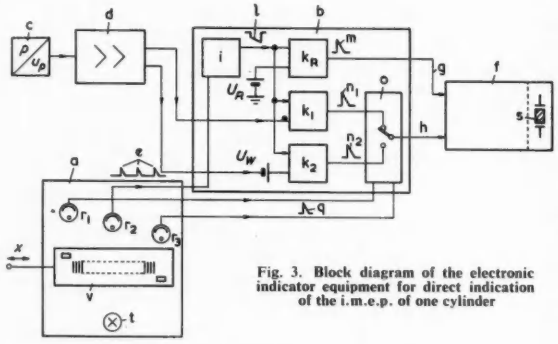

Fig. 3. Block diagram of the electronic indicator equipment for direct indication of the i.m.e.p. of one cylinder

the bridge output voltage u_p, which is proportional to pressure. When the voltage u_s drops to the value of u_p, (k_1) transmits the stopping impulse (n_1) to the counter (f).

When the piston changes its direction of motion on reaching the end of its outward stroke, the saw-tooth voltage should also change its direction (i.e., it should rise instead of falling), since p_1 and p_2 on the curves above and below the area representing work done are to be determined. To avoid technical difficulties, the saw-tooth curve was kept unchanged, and the direction of the bridge output voltage u_p was reversed for the return stroke, this being achieved by coupling the second connection of the push-pull output of the bridge to the circuit (k_2). Since the push-pull output voltage gives a voltage u_p which is negative at this connection, while the reference circuits can only operate with positive voltages, it was necessary to add to this negative output voltage a constant positive voltage U_w, obtained by means of a battery located between the second output connection and (k_2). Thus, the voltage $+u_p$ is applied to (k_1) and $-u_p+U_w$ is applied to (k_2). With increasing pressure p, the time elapsing between the starting impulse (m) and the stopping impulse (n_1) diminishes, whereas there is an increase in the time elapsed between the starting impulse (m) and the stopping impulse (n_2). This is in accordance with the conditions shown in Fig. 1, where increased values of cylinder pressure p correspond to a decrease in the area A_1 and an increase in the area A_2.

In order that, during a counting process, either (k_1) or (k_2) will operate, but not both simultaneously, the outputs of these reference circuits are not connected directly to the counter but are passed through current-control stages in a " gate " circuit (o). This gate[2] is controlled at the end positions of the piston-position indicator (a) by impulses (q) from photocells (r_1) and (r_3) in such a way that only impulses from (k_1) are passed through to the counter (f) during the power stroke, and only those from (k_2) during the idle stroke.

As already stated, the piston-position indicator (a) is coupled to the connecting rod by means of a stroke-reducing arrangement, whose main components are a light source (t) facing the three photocells (r_1), (r_2), and (r_3); between these and the light source is a long sheet-metal mask (v) provided with two end-slots which allow light to reach photocells (r_1) and (r_3) at the piston dead-centre positions, and also, uniformly distributed over its centre portion, 100 narrow slots, through which light, during brief intermittent periods, can impinge on photocell (r_2).

At the beginning of the measurement process, with the mask (v) at its extreme position on the left-hand side, the impulse from (r_1) connects the circuit (via an electronic switch not shown in Fig. 3) of the photocell (r_2) to the saw-tooth generator (i). At the same time, the gate (o) is switched, so that the current impulses from (k_1) can reach the counter. During the ensuing piston stroke, photocell (r_2) then triggers the saw-tooth generator (i) one hundred times. When the mask reaches its outermost position on the right-hand side, the impulse from photocell (r_3) reverses the connections of the gate (o), allowing the stopping impulses of the reference circuit (k_2) to reach the counter (f). The mask with its photocells is enclosed in a light-tight and dust-proof casing, and runs on ball-bearing supports in an accurately machined groove, so that the light impulse correspond to accurately defined positions.

The indicator control unit (b) must be fed from the measuring bridge with a voltage u_p proportional to pressure, reaching values up to a maximum of 100 V. A carrier-frequency bridge is used, with a d.c. push-pull output amplifier, and the pressure pick-up (c) is of the inductive type. When the bridge is balanced, the two push-pull output terminals have a zero potential. As the pressure rises in the pressure pick-up, the potential at the two output terminals increases by the same value, but with different polarities.

Extensive tests have shown that the complete indicating system is accurate to within about 1 %, so that its error is probably less than the indicating error of a cathode-ray oscilloscope unit.

Determination of I.M.E.P. from the Timer Data

The electronic timer provides values only in the form of numerical values, which may be denoted by z. The relation between these numerical values and cylinder pressure p is of the type $\Delta p = m\Delta z$, where m is a constant.

By means of the decreasing saw-tooth voltage, a measurement is taken of atmospheric pressure p_0, followed by measurement of a calibration pressure p_E, so as to have $p = p_E - p_0$. The corresponding numerical difference Δz is

$$\Delta z = z_R(p_R) - [z_2(p_0) + z_1(p_E)] \quad . . \quad (3)$$

where z_R is the numerical value representing the pressure ordinate p_R of the rectangular area A_R in Fig. 1, while $z_2(p_0)$ and $z_1(p_E)$ represent the pressures p_0 and p_E.

To determine z_R, the pressure pick-up (c) in Fig. 3 is connected to a hydraulic calibrator device. The pressure is set to ambient pressure p_0; by individual triggering of the saw-tooth signal, the value $z_1(p_0)$ is then obtained for decreasing saw-tooth voltage and, after reversing the gate (o), the value $z_2(p_0)$ for increasing saw-tooth voltage. In this way, z_R is determined as $z_R = z_1(p_0) + z_2(p_0)$.

Finally, the pressure is raised to the value p_E and the numerical value $z_1(p_E)$ is determined by triggering the saw-tooth voltage. The conversion factor m is then

$$m = \frac{\Delta p}{\Delta z} = \frac{p_E - p_0}{z_R(p_R) - [z_2(p_0) + z_1(p_E)]} \quad . . \quad (4)$$

and the indicated mean effective pressure p_{mi} is evaluated by means of the relation

$$p_{mi} = \frac{m}{100}\,[100\, z_R(p_R) - B^*] \quad . . \quad (5)$$

where $B^* = \sum_{n=1}^{100} z_{1n} + \sum_{n=100}^{1} z_{2n}$

and represents the numerical value of B at the end of a working cycle, with z_{1n} and z_{2n} as numerical values for p_{1n} and p_{2n}. Using the abbreviation

$$C = 100\, z_R(p_R) - B^* \quad .. \quad .. \quad (6)$$

the evaluation formula becomes

$$p_{mi} = mC/100 \quad .. \quad .. \quad .. \quad (7)$$

APPLICATIONS

The electronic method described is applicable, irrespective of whether the i.m.e.p. is to be determined from 1, 10, or any number of working cycles of a cylinder. It can also be extended so as to be used for simultaneous measurements on any number of cylinders, in which case each cylinder is fitted with a pressure pick-up, which is connected in turn to the counter equipment for the required number of working cycles by means of a rotary switch. An adjustable compensating resistor is included between each pick-up and the rotary switch, in order to adjust the pick-up voltage outputs in accordance with individual calibrations.

TEST RESULTS

I.m.e.p. tests have been carried out with this electronic equipment on a steam locomotive. In addition, comparative indicator diagrams were taken with mechanical equipment, and pressure diagrams with an electronic amplifier and an oscilloscope.

Altogether, 34 tests were carried out, at various i.m.e.p. values. Because the electronic counting system allows very rapid results to be obtained, its measurements were repeated several times during each test. The results of all three methods showed substantial agreement for 31 out of the 34 tests, the other three tests showing unexplained appreciable deviations in the range of the higher values of i.m.e.p. (90 to 135 psi). An interesting point is that, in nearly all these tests, the mechanical indicator diagrams gave the highest values, while the oscilloscope diagrams yielded i.m.e.p. values which were generally about 3 psi lower. The electronic counting method gave values which, in most cases, were close to, but slightly lower than, those derived from the oscilloscope diagrams. Apart from the unexplained results of the three tests mentioned, the values in the case of the other tests showed a scatter of less than 3%, except in five instances. As these were the first field tests, the accuracy obtained can be regarded as being very satisfactory.

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RUSSIA

Investigations into the Wear Resistance of Sprayed-Metal Deposits

By YU. D. PASHIN. (From *Vestnik Mashinostroyenia*, No..7, July 1959, pp. 65–68, 7 illustrations)

THE increasing use of metal-spraying for the reclamation of worn shafts and other machine components has stimulated interest in Russia in connection with research on the structure and wear resistance of sprayed-metal deposits. It is well known that, in the metal-spraying process, owing to the low temperature of metal particles at the instant of impact, oxidation of the deposited layers, and other factors, no alloying of the base metal and coating takes place, any interaction being purely mechanical. During investigations into the composition and macrostructure of the deposits, it has been found that they are composed of a wavy mass of particles arranged in layers parallel to the sprayed surface. Consequently, the strength of the deposit parallel and perpendicular to the surface of the base metal must have entirely different values. This latter phenomenons may easily be explained by the sequence of the metal-spraying process and the character of metal deposition.

For the reclamation of worn parts in Russia the type of spray guns generally used is that in which a wire is melted by the heating effect of an electric current and the molten particles are thrown by compressed air against the surface of the base metal in a cone-shaped jet, as shown in Fig. 1. From measurements carried out in order to establish the speed of the sprayed particles, it has invariably been found that the particles in the central zone (1) of the jet have a much greater speed than those in the peripheral zone. Even at a distance of from only 15 to 17 mm from the central zone, this discrepancy is considerable and has a great influence on the composition and character of the sprayed coatings.

During operation, as the spray gun is moved parallel to the longitudinal axis of the component (from left to right in Fig. 1), the peripheral particles (2) to the right of the gun first reach the base metal, building up a thin layer (3) on the surface of the reclaimed part, this being followed by the jet of central particles (1), which build up the main layer of metal deposition (4), and finally by the peripheral particles (5) to the left of the gun, which deposit another thin layer (6) on the surface of the main layer (4), The same sequence is repeated every time a new coating is deposited on the surface of the base metal,

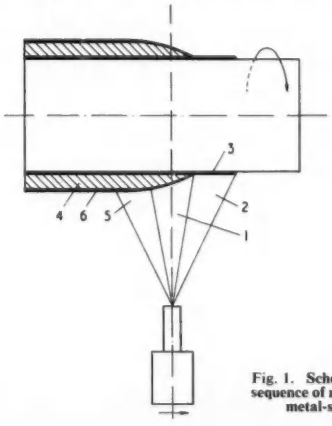

Fig. 1. Schematic diagram of the sequence of metal deposition in the metal-spraying process.

thus giving a stratified character to the coating, in which the particles deposited by the central part of the jet are separated by a thin and less coherent layer of peripheral particles. The number of these layers will be equal to the number of passes of the spray gun.

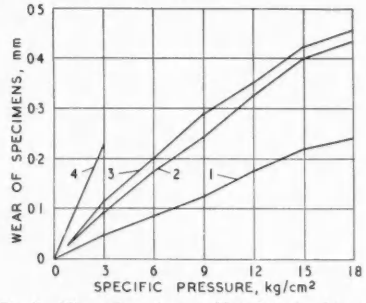

Fig. 2. **Wear of specimens subjected to dry friction.**

In order to evaluate the factors influencing the strength of sprayed-metal coatings in various directions, comparative tests were carried out on standard specimens, using a steel wire containing 0·7% carbon. The specimens were first sprayed with the jet of the gun adjusted at a wider angle, so that both the central and peripheral particles took part in the process of metal deposition. In this case, the strength of the coating parallel to the surface of the base metal was 12·42 kg/mm², while in the direction perpendicular to the surface of the base metal it was only 0·11 kg/mm². The jet was then adjusted in such a way that the peripheral particles were excluded from metal deposition, and in this case the corresponding strength values were 13·32 and 2·13 kg/mm² respectively. From these results it can be concluded that, in order to assess the true strength of sprayed-metal coatings, it is not sufficient to measure the strength in one direction only, e.g., parallel to the surface of the base metal, but also perpendicular to the surface.

To test various assumptions in connection with the wear resistance of layers deposited by the peripheral particles and to find out whether the wear resistance of coatings would be increased considerably if the plane of friction were perpendicular to the deposited layers, a series of tests, the results of which are shown in Fig. 2, was carried out on four types of specimens, i.e., (1) plain steel specimens containing 0·45% carbon, hardened to 45 Rc, (2) specimens sprayed with a carbon steel, with layers perpendicular to the plane of friction, (3) specimens sprayed with a carbon steel, with layers parallel to the plane of friction, and (4) specimens sprayed with a carbon steel, with layers parallel to the plane of friction, the coating being deposited by peripheral particles only. In this series of tests, the specimens were subjected to dry friction at specific pressures of 3, 6, 9, 12, 15, and 18 kg/cm², and it was found that (a) the plain steel specimens at every specific pressure had the greatest wear resistance; (b) the specimens with layers perpendicular to the plane of friction had only about 9 to 10% better wear resistance than those with layers parallel to the plane of friction; (c) the wear of coatings built up by the peripheral particles could only be measured at a maximum specific pressure of 3 kg/cm² since, owing to the presence of cavities in these layers, the coatings at higher pressures simply disintegrated. The inferior wear resistance noted in this case is a clear indication of the detrimental effect of peripheral particles if they are deposited on the surface or near the surface of sprayed-metal coatings.

The results of two further series of tests for studying wear resistance under conditions of sliding friction are given in Fig. 3, using (1) plain steel specimens containing 0·45% carbon, hardened to 45 Rc, (2) specimens sprayed with carbon steel, with layers perpendicular to the plane of friction, and (3) with layers parallel to the plane of friction. The results in Fig. 3a are based on the use of a lubricant comprising transformer oil containing 0·15% abrasive particles of about 5 microns grain size, while Fig. 3b refers to tests with a pure transformer oil. Specimens sprayed with peripheral particles could not be tested under conditions of sliding friction, owing to the high specific pressures involved. For the tests, bronze bearings were used, and the peripheral speed was 1·5 m/sec, the wear of specimens being measured at specific pressures of 15, 30, and 45 kg/cm². It is interesting to note that, when a pure lubricant was used, there was practically no difference between the performance of the plain steel and of the sprayed parts. However, when the lubricant contained abrasive particles, the plain steel specimens had superior wear resistance, while the wear resistance of specimens with layers perpendicular to the friction plane was about 7 to 8% better than that of those specimens with layers parallel to the friction plane.

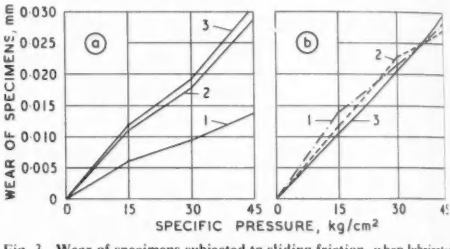

Fig. 3. **Wear of specimens subjected to sliding friction, when lubricated (a) with a transformer oil containing abrasive particles, and (b) with pure transformer oil.**

The relatively insignificant difference in wear resistance of coatings with layers parallel and perpendicular to the plane of friction in all these tests indicates that the wear of sprayed components takes place rather by attrition of the surface particles than by tearing away of the individual particles from the coatings. It is also evident that only negligible improvements in wear resistance can be expected by depositing layers perpendicular to the plane of friction of sprayed components.

Possible Approaches to Controlled Thermonuclear Fusion

(Concluded from page 358)

sought-after individual components. The magnetic probe consists of a small 20-turn coil, 2 mm in diameter, enclosed in an electrostatic shield mounted in the closed end of a tubular sheath of quartz or alumina. This projects radially into the discharge tube, and the coil is adjusted to the required radius and orientation.

Theoretical and experimental work is now directed towards an understanding of the mechanisms by which hot gas can slip through the confining magnetic field and be lost to the system. This knowledge is required before it is possible to have confidence that any of the now-known magnetic-field configurations will confine hot gas for the necessary time in a nuclear reactor.

The Atomization of Fuel Jets

By G. Sitkei. (From *Acta Technica Academiae Scientiarum Hungaricae*, Vol. 25, Nos. 1–2, 1959, pp. 87–117, 21 illustrations)

The efficiency of the working cycle of the diesel engine depends, to a considerable degree, on the effectiveness of fuel atomization. Afterburning, which frequently occurs, is in most cases due to insufficient atomization or to inadequate mixing of the fuel with air.

Smooth and complete combustion is facilitated by providing a mixture with a good macrostructure, i.e., a uniform distribution of fuel with the same fuel/air ratio in all parts of the combustion space, and a good microstructure, i.e., fine and homogeneous atomization. Fineness of atomization is characterized by the mean droplet diameter, and homogeneity by the deviation of the droplet diameters from this mean value.

In high-speed diesel engines, the amount of time available for mixture formation is very brief (3 to 5 millisec), so that the characteristic features of the jet, i.e., its depth of penetration, spray angle, and the distribution of fuel within the jet, are important. These features depend on design factors, such as nozzle design and combustion-chamber geometry, and on numerous physical factors such as the viscosity of the fuel, the injection pressure, the counter-pressure of the medium into which the fuel is injected, and air movement.

Disintegration of a Jet

The breaking up of a jet of injected fuel into fine droplets is the result of complicated processes, the mechanism of which is not yet fully clarified. It is known, however, that the jet is acted upon by internal and external forces, which ultimately cause it to disintegrate.

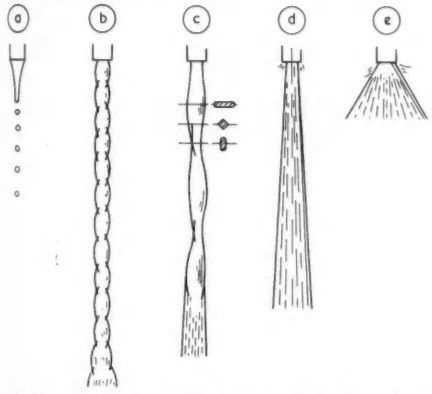

Fig. 1. Types of jets produced by various outflow velocities.

As soon as the jet is injected into the combustion chamber, it is subjected to the influence of external aerodynamic forces. Air resistance tries to tear particles out of the liquid and to disrupt the jet surface. This disrupting action increases in intensity when the jet surface is not smooth, i.e., when it contains initial disturbances due to inadequate surface finish of the nozzle, to conditions prevailing at the inlet and outlet edges of the nozzle, and to its length/diameter ratio. The surface tension of the fuel and the cohesive forces between the individual sections of the jet oppose these external forces.

In addition, there are internal forces due to turbulent flow conditions, and these are of considerable importance. The velocity vectors have a component perpendicular to the direction of flow, contributing to disintegration. Particles in turbulent and pulsating motion subdivide the jet into sections, and also cause a spreading of the spray proportional to the pulsation velocity.

Fig. 1 shows the characteristic forms of jet disintegration. At very low outflow velocities, the jet has a short, compact section, and the droplets break away owing to gravity (Fig. 1a). When the velocity is increased, the compact section becomes longer, and symmetrical ripples appear over its length (Fig. 1b). With a further increase in velocity, the length of the compact section decreases, and the disturbances become asymmetrical (Fig. 1c). Beyond a certain velocity, the jet envelope begins to disintegrate immediately after emerging from the nozzle. A still further increase in velocity increases the quality of atomization and also widens the cone angle (Figs. 1d and 1e). The velocities at which these characteristic patterns are formed depend on the physical properties (i.e., viscosity, surface tension, etc.) of the fuel; however, the L/D (length/diameter) ratio of the nozzle also has a considerable influence; tests have shown that, with nozzles having a small L/D ratio, the character of the flow depends considerably on the inlet conditions (pintle position, etc.). In this case, the flow characteristics are not fully defined by the Reynolds number.

Internal Forces

As mentioned above, when the velocity reaches a sufficiently high value, the jet breaks up into droplets immediately after leaving the nozzle. Thus, disintegration is mainly due to turbulent pulsations, assisted by the initial disturbances at the inlet and outlet edges.

In turbulent flow, the instantaneous value of velocity is $w = W_m \times w'$, where W_m = mean velocity and w' = instantaneous deviation from the mean. The intensity of the turbulence is characterized by the root-mean-square of the deviations, and the energy of the turbulent pulsation ε_r can be determined as

$$\varepsilon_r = \tfrac{1}{2}\rho\, u'^2 \qquad \ldots \qquad \ldots \qquad (1)$$

where ρ is the mass-density of the liquid.

Two other characteristic parameters of turbulent flow are the mixing length and the frequency of the turbulence. The maximum value of turbulence depends on the space available for the flow and on the Reynolds number, whereas its minimum value is determined by fluid viscosity. Between these two limits, all the intermediate values can also occur, with various frequencies, frequency increasing as the mixing length becomes shorter. It has been found experimentally that at higher velocities both the mixing length and the corresponding frequency of the turbulence tend to become greater.

If it is assumed that the energy of a turbulent pulsation is consumed in overcoming surface tension and in shearing the fluid at the pulsation velocity w', so as to form a droplet, then the energy of the pulsation referred to unit volume is

$$\varepsilon_r = (3\alpha/r_0) + A\mu\, w'^2$$

Since a sphere of surface $4\pi r_0^2$ has a volume $4\pi r_0/3$, a sphere of unit volume has a surface of $3/r_0$; therefore, the mean droplet radius is

$$r_0 = 3\alpha/(\varepsilon_r - A\mu w'^2) \quad .. \quad (2)$$

where α = surface tension coefficient, μ = viscosity, A = a constant, and $2r_0$ = mean droplet diameter immediately after emerging from the nozzle orifice. The droplets then break up further, owing to air resistance. Eq. (2) shows that the droplet diameter decreases when surface tension and viscosity are reduced and the pulsation velocity increases.

External Forces

With large bulge-shaped turbulences the jet breaks up immediately after leaving the nozzle and forms " strings " of droplets in the jet. The diameter of these droplets, determined from photographic recordings is, however, still fairly large. It is therefore reasonable to assume that the droplets are further subdivided by external dynamic forces.

The following relation exists between droplet radius r, surface tension α, and internal pressure:—

$$P = 2\alpha/r \quad .. \quad .. \quad (3)$$

where P = internal pressure due to surface tension. This expression does not clearly show the influence of external forces. If, however, the radius of a droplet increases by an amount $\triangle r$, the virtual work of internal forces is $4\pi r^2 P_i \triangle r$. This work is used in increasing the surface of the droplet and in overcoming external forces. Therefore, $4\pi r^2 P_i \triangle r = 8\pi r\alpha \triangle r + 4\pi r^2 P_a \triangle r$, and

$$P = P_i - P_a = 2\alpha/r \quad .. \quad (3a)$$

Thus, the forces due to internal pressure P_i and external pressure P_a both have an influence on the development of the droplet.

There are three cases to be considered. First, although P_i cannot be zero or less than zero, P_a may be zero, in which case the droplet is situated in a vacuum. Second, if $P_i > P_a > 0$, the droplet is in a state of equilibrium and does not change its size. The resultant pressure, directed outwards, is balanced by surface tension. In the third case, when $P_a > P_i$, the system is not in equilibrium; at any point the resultant force from the outside is directed inwards, in the same direction as the forces due to surface tension. To attain equilibrium again, the internal pressure must increase, with a corresponding decrease in droplet radius.

Under static conditions, the reduction in droplet size and surface area occurs without subdivision of the droplet, since the external pressure P_a is uniform around the droplet surface. When the droplet is in motion, however, eq. (3) is no longer applicable, since there is an additional force, due to air resistance, which acts on the frontal area of the droplet. This force causes a concave, C-shaped deformation of the droplet, spreading out towards the sides and becoming thinner in its centre section; finally, the C-shaped droplet splits into two parts.

As the dynamic pressure P_d required to disintegrate the droplet must be greater than $|P_a - P_i|$, or at least equal to this pressure difference

$$P_d \geq |P_a - P_i| = 2\alpha/r \quad .. \quad (4)$$

If R = force due to air resistance, and F = frontal area of the droplet,

$$P_d = R/F \quad .. \quad (5)$$

The value of R can be determined by means of the drag coefficient $\varphi = 12{\cdot}5/\sqrt{\mathrm{Re}}$, using Newton's equation, as

$$R = \varphi \rho_k F w^2 \quad .. \quad (6)$$

The Reynolds number $\mathrm{Re} = w d_T/\nu_k$, where d_T = droplet diameter, and ν_k = kinematic viscosity. The force-vectors R acting on the frontal area are parallel, with a maximum value R_0 at the centre section, and with $R = 0$ at the sides, and follow a circular distribution law, i.e.,

$$R(y)^2 = R_0^2\,[1 - (y/r)^2]$$

where y = perpendicular distance from the centre line to a point on the droplet periphery.

To facilitate calculations, Fig. 2 gives the kinematic viscosity ν_k [m²/sec] of air, gas compression pressure p_g [atm], temperature t_g [°C], and gas density ρ_k [kg/m³], as functions of the compression ratio in the engine cylinder, for the inditial conditions $p_0 = 0{\cdot}9$ atm and $T_0 = 328$°K. The graph shows that the kinematic viscosity decreases with increasing compression ratios.

Fig. 3 shows, plotted against droplet diameter d_T, the values of the additional dynamic pressure P_d which causes the breaking up of the droplets. The value of P_d decreases considerably towards the smaller diameters.

The minimum velocity required for the disintegration of the droplets will now be calculated. Solving eq. (6) for w (with $\varphi = 12{\cdot}5/\sqrt{\mathrm{Re}}$, it is found, according to Virubov[1], that

$$w_{crit} = [P_d \sqrt{d_T/\nu_k}/12{\cdot}5\rho_k]^{2/3} \quad .. \quad (7)$$

Curves of w_{crit} plotted against d_T, for various values of gas density ρ_k, are also given in Fig. 3. The w_{crit}-curves tend towards higher values for small droplet diameters. A further important result is that the value of w_{crit} decreases non-linearly when the compression ratio is raised. Between 5 and 11, w_{crit} is appreciably reduced, whereas it is only slightly altered from 11 to 18. This means that, in diesel engines, the droplet diameter is hardly affected by changes in the compression ratio.

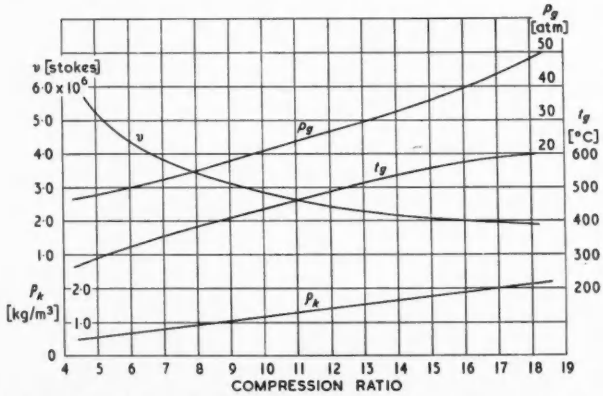

Fig. 2. Gas conditions in the combustion chamber as a function of the compression ratio.

Droplet Dynamics

The conditions of motion of fuel jets have been recorded photographically by many investigators, who have derived curves showing the penetration depth of the spray as a function of time. Unfortunately, none of these tests determined the velocity of the entrained air, or the

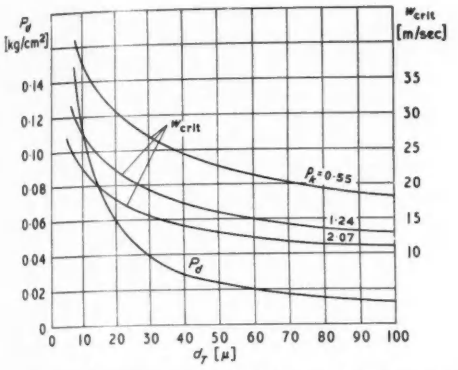

Fig. 3. **Aerodynamic pressure and critical velocity as a function of droplet diameter.**

velocity of the droplets relative to the entrained air. It is, however, probable that the air velocity rises steeply in the first period of injection, and decreases thereafter owing to friction and eddies.

As the droplet diameter and concentration vary throughout the cross-section, the velocity of the air flow occurring over the cross-section is also non-uniform. It is greatest at the centre, and tends towards zero around the outer surface and near the edges.

It may be assumed, therefore, that, if the air movement created by the piston or the chamber is disregarded, the movement of the particles near the outer surface of the jet takes place in a stationary medium. This assumption should be particularly applicable to the droplets which are generated during the first period of injection, which is important in regard to ignition.

The laws of motion of these droplets can also be determined analytically. The differential equation of droplet motion is

$$-\varphi_k \rho_k F w^2 = (V\gamma_b/g)\, \mathrm{d}w/\mathrm{d}t$$

where γ_b = specific weight of the fuel. Since $\rho_k g = \gamma_k$, and $F/V = 3/r = 1{\cdot}5/d_T$,

$$-\mathrm{d}w/\mathrm{d}t = \varphi_k(\gamma_k/\gamma_b)\,(1{\cdot}5/d_T)w^2 \qquad .. \quad (8)$$

Now, $\mathrm{Re} = wd_T/\nu_k$ and $\mathrm{dRe}/\mathrm{d}t = (\mathrm{d}_T/\nu_k)\mathrm{d}w/\mathrm{d}t$, so that the relation becomes

$$-\mathrm{dRe}/\mathrm{d}t = \varphi_k(\gamma_k/\gamma_b)\,(1{\cdot}5\nu_k/d_T{}^2)\,\mathrm{Re}^2$$

or, after substitution of $\varphi_k = 12{\cdot}5/\sqrt{\mathrm{Re}}$,

$$\mathrm{dRe}/\mathrm{d}t = 2K\,\mathrm{Re}^{1{\cdot}5} \qquad .. \quad (9)$$

with $K = 9{\cdot}375(\gamma_k/\gamma_b)\nu_k/\mathrm{d}_T{}^2$. By integration of eq. (9)

$$\mathrm{Re}^{-0.5} - \mathrm{Re}_0{}^{-0.5} = K\sqrt{\nu_k/d_T} \times t$$

or

$$w^{-0.5} - w_0{}^{-0.5} = K\sqrt{\nu_k/d_T} \times t \qquad .. \quad (10)$$

Eq. (10) enables the velocity of droplets of various diameters with an initial velocity w_0 to be calculated as a function of time. From the example given in Fig. 4 (with w_0 = 100 m/sec), it can be seen that the droplets with diameters of 10 to 20μ rapidly lose their velocity, and, after 0·1 millisec, move practically with the air stream, whereas droplets retain their spherical shape up to the end, and their initial velocity.

In the above calculations, it was assumed that the droplets retain their spherical shape up to the end, and that their diameter is not altered. It has already been shown, however, that the droplets break up when the dynamic pressure due to air resistance exceeds the pressure due to surface tension.

Unfortunately, the number od droplets which are formed in this disintegration process is not known. The larger droplets, with P_a-values far in excess of $2\alpha/r$, probably break up into more than two droplets, whereas only two new droplets are formed from the droplets of smaller diameter. If it is assumed that each subdivision results in the formation of two droplets from one, the number of separations necessary to reach a minimum diameter can be determined from a given droplet diameter. A droplet of initially 80 μ in diameter, for instance, is divided into 2 droplets of 64 μ, 4 of 50 μ, 8 of 40 μ, etc.; 6 subdivisions are required to reach 20 μ, 7 to reach 16μ,and 8 to reach 13 μ. Thus, there is a reduction in diameter of 20 μ in the first subdivision, whereas three subdivisions are required to obtain a reduction in size from 20 μ to 10 μ. This fact confirms the practical observation that droplets with diameters below 15 to 20 μ can only be obtained from an unduly high injection pressure.

If it is further assumed that, in this process of division, the individual subdivisions occur with the same time constant, curves can also be constructed for the velocity of droplets of variable diameter.

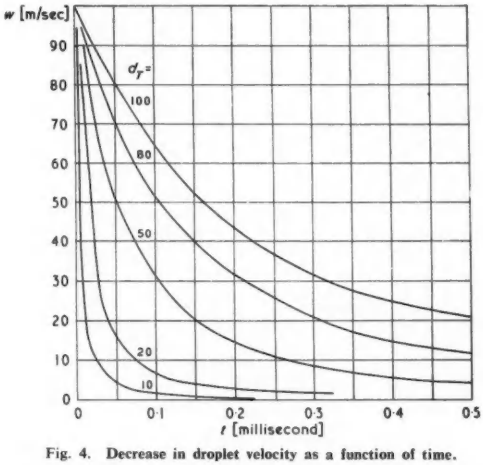

Fig. 4. **Decrease in droplet velocity as a function of time.**

It may be assumed that the time required for the shearing of a droplet into two parts is approximately proportional to the reciprocal of the velocity gradient $\mathrm{d}u/\mathrm{d}z$ in its boundary layer, so that, taking account of Newton's equation for the magnitude of the viscous shear force in a fluid,

$$P_s = \mu F\, \mathrm{d}u/\mathrm{d}z \qquad .. \qquad .. \quad (11)$$

The equation of the forces acting on the droplet is

$$R = P_s + P_a$$

where P_a represents the force required to overcome surface tension. With $F = d_T^2/4$ = area of the meridian section of the droplet, R from eq. (6), and $P_a = \pi\alpha\, d_T$, the above equation gives

$$\mathrm{d}u/\mathrm{d}z = (\varphi_k \rho_k d_T w^2 - 4\alpha)/\mu d_T$$

This equation clearly shows that $\mathrm{d}u/\mathrm{d}z$ decreases when surface tension and viscosity are increased, and that therefore the value of $\triangle t$ increases.

It is permissible to assume that there is a linear velocity distribution in the boundary layer of thickness δ. The result obtained is then

$$u = \delta(\varphi_k \rho_k d_T w^2 - 4\alpha)/\mu d_T$$

The time required for division to take place can be determined approximately as

$$\triangle t \simeq d_T/u = \mu d_T^2/[\delta(\varphi_k \rho_k d_T w^2 - 4\alpha)] \quad .. \quad (12)$$

As, during the subdivisions, the velocity decreases approximately in proportion to the droplet diameter, the time $\triangle t$ elapsing between two successive subdivisions of the droplet can be regarded as approximately constant.

Mean Droplet Diameter

An expression will now be derived for the mean droplet diameter d_m after n subdivisions, as a function of the physical constants of the fuel and various parameters of the injection process.

Subdivisions can occur only until a velocity w_{crit} is reached. The energy expended up to this stage is

$$E = \tfrac{1}{2} m_0 (w_0^2 - w_{crit}^2) \quad .. \quad (13)$$

The number of subdivisions is

$$n = \log_e(d_0/d_m)/\log_e 0{\cdot}8 \quad .. \quad (14)$$

where d_0 = initial diameter. The energy is used in overcoming surface tension and in shearing the droplets; hence, it can be expressed as

$$E = \alpha \pi d_0^2 (F^* - 1) + (\mu/4) F^* (u/\delta) D \pi d_0^3 \quad .. \quad (15)$$

where

$$F^* = \sum_{n=0}^{n} (1/0{\cdot}8^n) \text{ and } D = \sum_{n=0}^{n-1} (1/0{\cdot}8^n) \times \sum_{n=0}^{n-1} (1/0{\cdot}8^{2n})$$

With $d_0 = d_m/0{\cdot}8^n$, it can be shown that

$$d_m = \alpha \sum_{n=0}^{n-1} 0{\cdot}8^n \Big/ [A(w_0^2 - w_{crit}^2) - (\mu B D)] \quad .. \quad (16)$$

where A and B are constants. Thus, the breaking-up process is resisted by increased values of α and μ, and, smaller droplet diameters are obtained by raising the value of w_0, for instance by using a small-diameter nozzle. These results agree with experience. Eq. (16) also takes account of the density of the gaseous medium, since w_{crit} is a function of ρ_k. For most fuels the value of α is approximately the same, but μ can vary considerably. With a high μ-value, $\triangle t$ is increased, and d_m also becomes greater.

Depth of Jet Penetration

Tests have shown that the individual droplets are only capable of covering a distance of about 25 mm in the chamber, whereas the entire jet can cover distances of 250 mm or more. The calculation must therefore be applied to the entire jet.

The droplets situated on the jet surface break up owing to the resistance of the surrounding medium, and lose some of their velocity and energy in this process. With turbulent motion, a radial component of velocity is always present, owing to which the droplets can move in the transverse direction. The positions of the droplets separating from the frontal area of the jet are taken up by new droplets which still have sufficient energy.

The calculation will be made by assuming (1) that the jet is of conical shape, with a hemispherical end portion; (2) that it can be regarded as a compact and continuous body; and (3) that the injection pressure and the initial velocity remain unchanged throughout the injection process.

The resistance acting on the frontal area of the jet is

$$R = \varphi_s \rho_k F_s w^2 \quad .. \quad (17)$$

where ρ_k = mass-density of the surrounding medium. The drag coefficient φ_s of the jet, according to tests carried out at the I.C. Engine Research Institute, Leningrad, can be expressed as a function of Reynolds number. Thus,

$$\varphi_s = 405/\sqrt{\text{Re}} \quad .. \quad (18)$$

Pure turbulence is obtained if the Reynolds number in the nozzle bore is not less than 6500. This critical value will be denoted by Re_0. Therefore, from eq. (18), it follows that

$$\varphi_{crit} = 405/\sqrt{6500} = 5{\cdot}03$$

Also, $\text{Re}_0 = v_0 d_c/\nu_b$, where d_c = nozzle diameter, and ν_b = kinematic viscosity of the fuel. If P = injection pressure, and P_g = pressure in the chamber, the initial velocity v_0 can be determined from

$$v_0^2 = \varphi_s^2 \times 2g(P - P_g)/\gamma_b$$

γb_b being the specific gravity of the fuel. Substituted in eq. (17), this gives the resisting force acting on the jet as

$$R = 5{\cdot}03\,(\text{Re}_0/\text{Re})^{0{\cdot}5} \rho_k F_s v^2$$

With $\text{Re} = v d_s/\nu_k$, $\nu_k = \mu_k/\rho_k$, and $F_s = \pi d_s^2/4$, where d_s = jet diameter, this expression can be rewritten as

$$R = 3{\cdot}77 \sqrt{v_0 d_c \rho_k \rho_b} \sqrt{\mu_k/\gamma_b} \times d_s^{1{\cdot}5} v^{1{\cdot}5} \quad .. \quad (20)$$

which is valid for any value of v, with $\text{Re} > \text{Re}_0$.

The quantity of fuel injected in one working cycle is

$$m = (\pi d_c^2/4)\, v_0 \rho_b \tau'$$

τ' being the duration of injection. In crank-angle degrees, $\tau' = \theta^\circ/(360^\circ N/60) = 60\, z/N$, with $z = \theta^\circ/360^\circ$ and N = engine speed in rpm. Therefore,

$$m = 15\pi\, d_c^2\, v_0\, \rho_b\, z/N$$

The equation of motion is $R = -m\mathrm{d}v/\mathrm{d}t$. Substituting m, using eq. (17), and integrating from 0 to t

$$v = v_0/(1 + Ct)^2 \quad .. \quad (21)$$

where $C = 0{\cdot}04(N/z)\sqrt{(\gamma_k/\gamma_b)\,(\mu_k/\mu_b)} \times (d_s/d_c)^{1{\cdot}5}$

In the above expressions, the jet diameter d_s is a variable quantity, which has to be determined from tests. The calculations should be made for fairly small time intervals to allow variable quantities to be treated as constants. The distance L covered by the jet is

$$L = \int_0^t v\mathrm{d}t = v_0 t/(1 + Ct) \quad .. \quad (22)$$

The values of v and L obtained from these formulae are in good agreement with experimental results. If Re_0 is below 6500, its value should be used in eq. (18) to determine the value of φ. The value of v_0, as a function of the injection pressure P, can be estimated from $v_0^2 = \varphi^2(2gP/\gamma_b)$.

Thus, taking account of eq. (22), it is seen that the distance covered by the jet depends only on time and

pressure. For instance, if L [mm] is plotted against $t\sqrt{P}$ [sec $\sqrt{\text{atm}}$], using the experimental results available [2,3], all the points are situated on a single curve, with $L = 0$ for $t\sqrt{P} = 0$, $L = 100$ for $t\sqrt{P} = 0{\cdot}048$, and $L = 150$ for $t\sqrt{P} = 0{\cdot}114$.

In eq. (22), the nozzle hole diameter d_c appears in the denominator. To take account of various values of d_c, eq. (22) can be rewritten as

$$L = v_0 t/[1 + (A/d_c^{1.5})] = v_0 t\, d^{1.5}/d_c^{1.5} + A)$$

and the general relationship is given by

$$L/d_c^n = f(t/d_c^n) \qquad .. \qquad (23)$$

Only spring-loaded injection systems (e.g., the Jendrassik system) have an injection rate unaffected by a change in nozzle diameter. With cam-controlled injection, the velocity of injection increases when d_c is reduced. The extent of this increase is also considerably dependent on the capacity of the system, which comprises the delivery valve, the pressure pipe, the nozzle volume, etc. In modern designs the values of the exponent n vary around unity.

When the pressure of the gaseous medium is varied, the results can be expressed as $L = f(t/\sqrt{\rho_k})$ where ρ_k = mass-density of the medium. Finally, an even more general relationship, taking account of t, P, d_c and ρ_k, can be derived to represent experimental results in the form

$$L/d_c = 7{\cdot}4\,[\log_e (t\sqrt{P}/d_c\sqrt{\rho_k})]^{2.4} \qquad .. \qquad (24)$$

Cone Angle of the Jet

If the L/D ratio of the nozzle is sufficiently large, the cone angle of the jet, for a given back pressure of the gaseous medium, is only a function of the turbulent pulsation determined by the Reynolds number. In practice, however, the L/D ratio is fairly small, so that the flow is not fully defined by its Reynolds number. Moreover, the shape of the inlet section and the design and position of the pintle give rise to initial disturbances which have a considerable effect on the flow pattern.

However, if the cone angle is known for a given back pressure, its variation can to some extent be predicted.

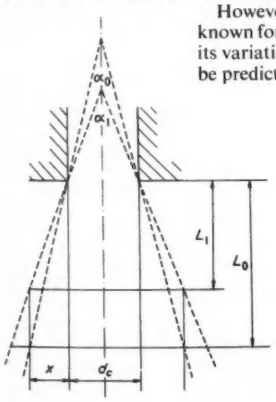

Fig. 5. Cone angle of jet.

As the spreading of the jet is due to internal turbulence and to initial disturbances, the width of the jet after a certain time t will reach a value which will remain the same irrespective of back pressure. Since, on the other hand, the distances covered by the jet are different for various ρ_k-values, the cone angle α will vary. From Fig. 5 it is seen that

$$x/L_0 = \tan(\alpha_0/2) \text{ and } x/L_1 = \tan(\alpha_1/2)$$

so that

$$\alpha_1 = 2\tan^{-1}[(L_0/L_1)\tan(\alpha_0/2)] \qquad .. \qquad (25)$$

Taking account of eq. (22),

$$L_0/L_1 = (1 + c\sqrt{\sigma_{k1}})/(1 + c\sqrt{\sigma_{k2}})$$

and the expression for α_1 becomes

$$\alpha_1 = 2\tan^{-1}(A + B\sqrt{\sigma_{k1}}) \qquad .. \qquad (26)$$

The general trend of the curve represented by eq. (26) is in good agreement with test results, for instance with those published by Sass.[4].

Similarly, the influence of nozzle-hole diameter on the cone angle of the jet can be expressed by the relation

$$\alpha_1 = 2\tan^{-1}[A + (B/d_{c1}^{1.5})] \qquad .. \qquad (27)$$

which is also based on eq. (22). These equations assume that the outflow velocity v_0 does not vary when the nozzle diameter is changed. In practice, however, this is not so; a reduction of d_c causes an increase in v_0 for a given cam profile and running speed. When this is taken into account, the effect on α of increasing the hole diameter becomes much less important.

As regards injection pressure, it may be noted that any change in P will also alter the rate of injection; this affects the turbulence and the initial disturbances. Unfortunately, experimental data on these factors are too scarce to permit theoretical analysis. It is only known that, with an increased rate of injection, the turbulence and initial disturbances are also increased, resulting in a wider cone angle of the jet. However, the distance L_1 also becomes greater than L_0, and this reduces the value of α. The cone angle becomes wider mainly at comparatively low velocities; at high velocities, it remains fairly constant.

Fuel Distribution in the Jet

The distribution is non-uniform along the length and throughout the cross-section of the jet. In the case of a cylindrical hole, the emerging jet spreads out continuously, as a result of large internal pulsations and also because of the aerodynamic forces acting on its frontal area. The development of the jet probably occurs in the following manner. At the beginning of injection, the velocity of the emerging particles is rapidly reduced by air resistance; at the same time, however, more favourable conditions are created for subsequent particles. At a certain distance the particles situated in front are driven towards the sides by air resistance and are replaced by others which still have sufficient kinetic energy. These, in turn, soon lose most of their energy, and the process repeats itself. The air carried away by the particles on the jet surface also takes part in the atomization process. Moreover, the concentrated, large-scale internal turbulence occurring in the vicinity of the surface reduces the compactness of the jet. Thus, a compact central core with considerable energy is formed at the centre of the jet. The particles move round this core and gradually reach the outer surface, decreasing in size and losing their velocity. These small particles are then capable of rapidly adapting themselves to the velocity of the air stream. Thus, good mixing conditions are obtained.

Various attempts have already been made to determine theoretically the distribution of the fuel in the jet. Calculations, however, give only approximate values.

Let Q = quantity of fuel present in a cross-section F at a distance x from the nozzle hole (see Fig. 6). Then the

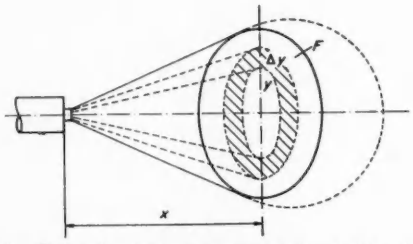

Fig. 6. **Explanation of the symbols used in the calculation of fuel distribution in a cross-section.**

quantity of fuel per unit solid angle (known as the " fuel flux ") can be determined as

$$f_Q = Q/(F/x^2) = Qx^2/f \text{ [gm/steradian]}$$

F/x^2 being the solid angle of the jet at a distance x from the nozzle outlet.

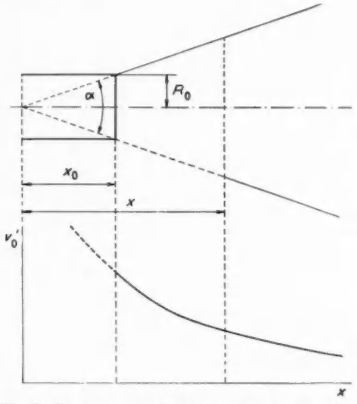

Fig. 7. **Jet geometry and velocity along the jet axis.**

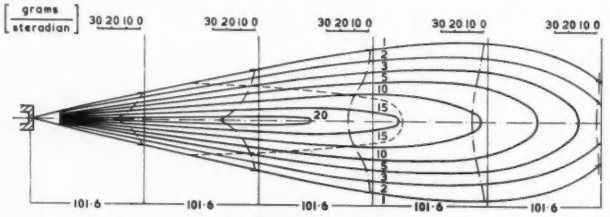

Fig. 8. **Fuel flux and fuel distribution curves.**

The " specific fuel flux ", which characterizes the distribution of 1 gram of fuel in a given cross-section, is

$$f = (Q/Q_0)x^2/F$$

where Q_0 = total quantity of fuel injected.

For the sake of simplicity, it will be assumed that f is constant in any cross-section. If f_{yQ} is the fuel flux and f_y the specific fuel flux at a radius y (see Fig. 6), then the quantity of fuel within an annulus of width dy is

$$dQ = (f_{yQ}/x^2)\ 2\pi y dy$$

and the fuel over the entire cross-section is

$$Q = (2\pi/x^2)\int f_{yQ} y dy$$

integrated from $y = 0$ to $y = b/2$. The relative quantity of fuel in the cross-section is $q = Q/Q_0$.

To perform the integration, the distribution of f_{yQ} over the cross-section must be known. As it is proportional to velocity, the velocity distribution must be determined. Experimental investigations of free jets have shown that the distribution of velocity in a given cross-section can be represented by

$$v_y = v_0' e^{-h^2y^2} \quad .. \quad (28)$$

which gives a symmetrical curve with a maximum at its centre. v_0' is the velocity along the axis of the jet, and h is a distribution constant, which can be determined approximately from

$$h^2 = c\mu_b d_c/(v_0\sigma_k x^2) \quad .. \quad (29)$$

where c is a constant. With this value and v_0' determined in the same way as v in eq. (21), the value of v_y can be calculated. From these considerations, it follows that f_y can be represented as

$$f_y = f_0 e^{-h^2y^2} \quad .. \quad (30)$$

where f_0 = specific fuel flux along the axis of the jet. After substituting and integrating, the result is

$$q_k = (2\pi f_0/2h^2x^2)(1 - e^{-h^2b^2/4}) \quad .. \quad (31)$$

It is advisable to determine $f_0 = f(x)$ experimentally. Where this is not practicable, the velocity v_0' along the jet axis can, according to Abramovich[5], be estimated as

$$v_0'/v_0 = 0{\cdot}96R_0/(\alpha x) \quad .. \quad (32)$$

where R is the nozzle radius. Instead of $0{\cdot}96/\alpha$, it is more appropriate to use $\tan(\alpha/2)$ in this expression (see Fig. 7), so that the expression for the specific fuel flux becomes

$$f' = f_0R_0/[\tan(\alpha/2)\ x] \quad .. \quad (33)$$

Taking the logarithms of both sides, eq. (30) yields

$$\log_e f_y = \log_e f_0 - h^2y^2 \quad .. \quad (34)$$

These relations are valid for $x > x_0$. With $\log_e f_y$ as the ordinates, and y^2 as the abscissae, a family of straight lines is obtained. For any given cross-section, it will be sufficient to find the y-value of f_y for any two abscissae y^2 to define the diagram by means of test results.

Fig. 8 shows the characteristic distribution curves as functions of the specific fuel flux. The chain-dotted curves indicate the distribution in the corresponding cross-sections, with scales of values in grams per steradian indicated horizontally. It is seen that the distribution becomes increasingly more uniform as the distance x from the nozzle increases, and that the compactness of the central portion is gradually reduced. The diagram also shows that the quantity of fuel reaching a specified cross-section decreases as the distance from the nozzle becomes greater. By increasing the back-pressure of the surrounding medium, the distribution is made more uniform; it is also improved by reducing the nozzle diameter and by raising the injection pressure.

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New Type of Variable-Speed A.C. Motor

By P. K. CHARLU. (From *Power Apparatus and Systems* (*A.I.E.E.*), No. 42, June 1959, pp. 407–413, 9 illustrations)

WHEN a balanced polyphase alternating current is suitably connected to the stationary brushes of an armature of a d.c. machine, a rotating magnetic field is produced, revolving at synchronous speed. In addition, if the brushes were to be rotated at synchronous speed in a direction opposite to the direction of the revolving field, then the field flux would become stationary. If the armature were also rotated, then the field flux would still be stationary, but its magnitude and phase displacement in space would vary, depending on the speed and the direction of the rotation of the armature. When the armature is rotated in the same direction as the rotating brushes, the armature takes lagging current. With an increase in speed the current decreases, so that the field flux decreases and shifts in space in the direction of rotation. However, if the armature were to be rotated in the opposite sense with respect to the revolving brushes, the armature induced voltage reverses and takes leading current. In the case where the armature is stationary, it behaves like a resistance. Thus, the behaviour of the machine for different speeds and directions of rotation is similar to the case of the Scherbius type of phase advancer sometimes used in variable-speed drives.

If the stator were to be excited with a d.c. supply, the magnetic field produced by the poles would react with the field produced by the armature and torque might result, depending on the relative space positions of the two fluxes. The maximum torque per unit ampere is obtained for a given stator field when the two fields are in space quadrature. The direction and the rotation of the torque would depend on the relative directions of the stator field and the armature current. The operation of the machine is almost similar to the "synchronous flux machine", with the output frequency, phase angle, and torque angle independent of the armature speed, except that, in this case, direct current is used for the field excitation of the stator and hence stationary field flux is produced. However, when the field is considered with respect to the brushes, it revolves at synchronous speed in the opposite sense.

The speed and power factor are easily adjusted by either varying the d.c. field excitation or the voltage applied to the armature, or advancing or retarding the synchronously revolving brushes. The advantage, as far as the armature control is concerned, is that control is easily accomplished by variacs, a twin-induction regulator, etc., whereas in d.c. motors it requires more cumbersome devices. It is assumed that adjustment of the phase of the rotating brushes with respect to the supply voltage changes the torque-angle operation of the motor, whereas varying either the magnitude of the d.c. excitation or the voltage applied to the armature does not vary the torque angle, unless accompanied by a shift in phrase.

Experimental Equipment and Procedure

Tests were conducted on a generalized rotating electromechanical power modulator (Fig. 1), developed at the Massachussetts Institute of Technology. The four coils on the stator of the generalized machine were connected to form a 2-pole arrangement when excited by a d.c. source. A 25-cps 2-phase supply was provided for the rotating brushes, using a diametric connection. The brushes were driven by gears, using a synchronous induction motor, with an electrical phase-shifting arrangement for shifting the phase of the brushes. A stroboscope, synchronized to the supply of the brush drive motor, was used to read the phase shift of the brushes. A d.c. motor was coupled to the main shaft of the generalized machine to drive it as a generator or to load it as a motor. The brush-carriage drive motor used for the tests was a 2-pole, 3-phase wound-rotor induction motor, with the stator connected to the 25-cps supply and the rotor connected to a d.c. source through an electrical phase shifter.

The speed of the motor-alternator set supplying the 25 cps for the experiments was maintained constant by using a stroboscope synchronized to the 50-cps supply to the laboratory. In addition, the output voltage of the set was maintained constant. The brush drive motor was run in an overexcited state to increase its stability of operation and to reduce its torque-angle change due to variation in the brush friction of the generalized machine.

To check the polarity of the connections, using the d.c. motor, the machine was run as an alternator in the direction of rotation of the synchronously revolving brushes, so that the voltage applied to the brushes was in phase opposition to the e.m.f. generated in the machine. The final position of the sliding brushes of the phase shifter to give the foregoing condition was noted, this being taken as the zero reference position. Owing to the difference in the waveforms, a difference in potential of 2 V was observed across the switch before it was closed. However, the procedure just described is not necessary if connections are made properly and if the respective polarities are taken into account. Then, the machine can be started as a motor, applying reduced voltages to the rotating brushes.

If direction of rotation of the armature in the opposite sense to the rotating brushes is desired, it is easily effected

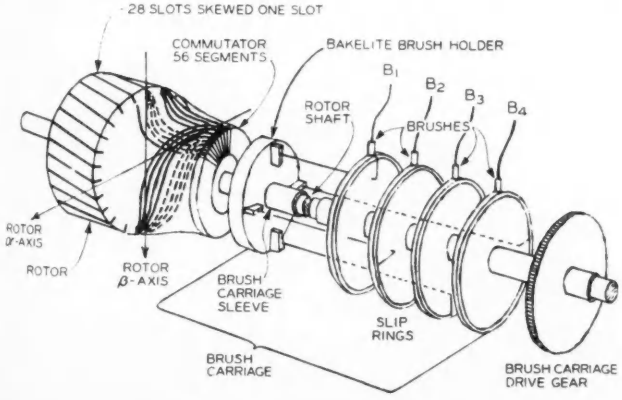

Fig. 1. Generalized rotating electro-mechanical power modulator.

either by reversing the d.c. supply to the stator of the machine or by reversing the d.c. supply to the rotor of the brush drive motor.

Also, it was noted that, when the brushes were not running at synchronous speed but with a small slip, obtained when the d.c. supply to the brush drive motor was switched off with the resistances across its rotor terminals, and when a low voltage was impressed on the rotating brushes, the armature oscillated in either direction, similar to a separately excited shunt motor with its armature terminals connected to a d.c. series generator. At higher values of slip the machine vibrated at high frequency.

Test Results

The no-load saturation characteristics of the generalized machine for 2-phase operation as an alternator at 1200 rpm and 1800 rpm, with the rotating brushes at synchronous speed, are shown in Fig. 2. Also shown are the d.c. no-load saturation characteristics at the same speeds, with the brushes stationary and aligned to the geometric neutral axis. The d.c. value is 1·58 times the r.m.s. a.c. value at the diametric brushes.

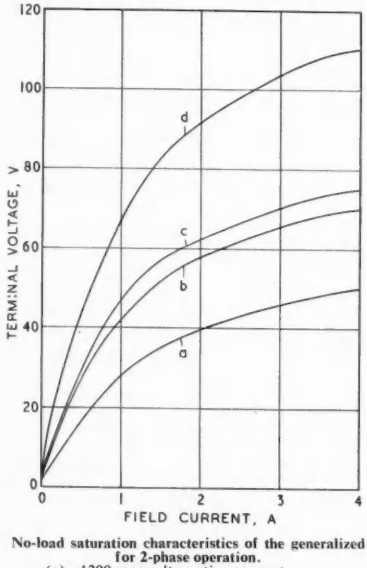

Fig. 2. **No-load saturation characteristics of the generalized machine for 2-phase operation.**
(a) 1200 rpm, alternating current.
(b) 1800 rpm, alternating current.
(c) 1200 rpm, direct current.
(d) 1800 rpm, direct current.

The no-load speed characteristics for 2-phase operation of the generalized machine as a motor, with the armature rotating in the direction of the brushes, are shown in Fig. 3, in which curves (a) and (b) represent speed as a function of voltage for field currents of 2·5 and 1·5 A respectively, while curves (c) and (d) show speed as a function of field current for voltages of 30 and 50 V respectively. It should be noted that these characteristics are similar to those of a d.c. shunt motor.

If it is necessary to start the machine so that the current is always kept at the minimum corresponding to the unity power-factor condition, then the brush position should also be adjusted. It was found that the best position for the shift of the brushes was about 5-deg. retard from the zero reference position while the armature accelerated to the desired subsynchronous speed on no load. If the brushes are retarded still more, the power factor becomes leading, and if retarded less, it becomes lagging at higher speeds. However, for supersynchronous speeds it is necessary to reduce the angle of retard to about 3 deg. on no load.

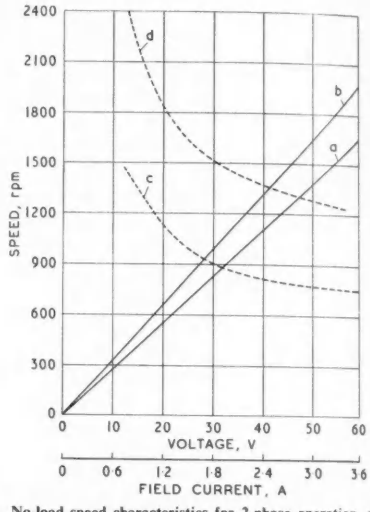

Fig. 3. **No-load speed characteristics for 2-phase operation, showing speed as a function of voltage with field currents of (a) 2·5 A, and (b) 1·5 A, and as a function of field current with voltages of (c) 30 V, and (d) 50 V.**

The machine operating at constant voltage, field excitation, and brush shift drops in speed when loaded, and the power factor shifts towards the lagging side. The drop in speed, from no load to full load, for a particular setting of the brush shift, voltage, and field current, varies from 15 to 25%, depending on the initial no-load speed.

An increase in speed can be obtained, just as in the case of an ordinary d.c. motor, by retarding the brushes, by increasing the applied voltage across the armature, and by reducing the field excitation.

In a synchronous motor, lagging and leading power factor produce respectively magnetization and demagnetization of the field flux. Similarly, in the case of the generalized machine, lagging power factor produces a magnetizing effect, and reduction in speed results, whereas leading power factor magnetizes and hence increases the speed.

The variation in power factor is much more sensitive to changes in voltage, field current, and brush shift under no-load conditions than at higher values of load. It may be noted that a parallel condition exists in the case of a synchronous motor when the field excitation is adjusted. Again, it was noticed that the variation in power factor was less sensitive to changes in brush shift and field current at the lower speeds when the applied voltage was low. This is true for either direction of rotation of the armature with respect to the rotating brushes, and variation in power factor becomes more and more sluggish at higher loads. Also, power-factor change is much more sensitive to changes in brush shift than to changes in field excitation or voltage.

In the case of the armature rotating in the direction opposite to that of the brushes, it should be noted that,

with constant voltage, field excitation, and brush shift, the machine under load drops in speed, but the power factor shifts towards the leading side, contrary to normal expectations. As a result, a leading power-factor condition produces a magnetizing effect similar to an alternator condition, and *vice versa* for a lagging power factor. To obtain an increase in speed, adjustments are made which are similar to those in the case of rotation in the same direction as the brushes, except that the brush shift must be applied in the opposite sense.

Single-Phase Operation:—

The no-load speed characteristics for single-phase operation, with the armature rotating in the same direction as the brushes, are shown in Fig. 4, in which curves (a) and (b) represent speed as a function of voltage for field currents of 3 and 2 A respectively, while curve (c) shows speed as a function of field current for a voltage of 50 V. It will be noted that these characteristics are basically similar to those for 2-phase operation, as shown in Fig. 3.

It was found that, under load, the drop in speed varies from 10 to 20% for various no-load speed settings, the power factor moving towards the lagging side under load, as in the case of 2-phase operation.

In the case of single-phase operation with the armature rotating at a no-load speed of 1000 rpm in the opposite direction to that of the brushes, the motor takes leading current, instead of lagging current, as in the case of two-phase operation with a similar reverse sense of rotation.

Commutation

When the machine is started, the reactance voltage produced is solely the result of the inductance of the coils undergoing commutation similar to the condition of a stator-fed commutator motor at synchronous speed. At synchronous speed, the reactance voltage due to the inductance of the coil vanishes, but two-speed e.m.f.'s are produced, the first due to the main-pole flux and the second due to the armature reaction field. These two voltages will be displaced 90 deg. in space and time. At any other speed the reactance voltage produced is the result of all three causes. In single-phrase operation, the problem of commutation is even more complicated, because of the addition of the third-harmonic current and the double-frequency component in the stator field flux.

The problem of commutation in 2-phase and single-phase operation has not been studied in detail, but the experimental machine, although small, has given absolutely no trouble from commutation. By the use of special windings, it should be possible to improve commutation in larger units. Also, arrangements could be incorporated to minimize the voltage induced by armature reaction flux, through the use of interpoles excited by rectified currents proportional to the line currents. In addition, if the position of the rotating brushes has to be altered, a special provision of an electrical phase-shift arrangement for the interpoles should be provided. If salient poles are used, then it may be necessary to split the poles into two halves to reduce commutation trouble along the axis of the field flux.

Operation as an Autosynchronized Converter

Since the machine is self-starting and the armature flux is always stationary, it can easily be seen that, by providing additional stationary brushes in the brush axis, it should be possible to operate the machine as a converter. In this case, interpoles excited by the direct current could be used. Nevertheless, the machine will have the same limitation as a normal synchronous converter, insofar as power-factor variation is concerned, because of the uneven heating of the armature conductors. However, if arrangements are made to shift the brushes with

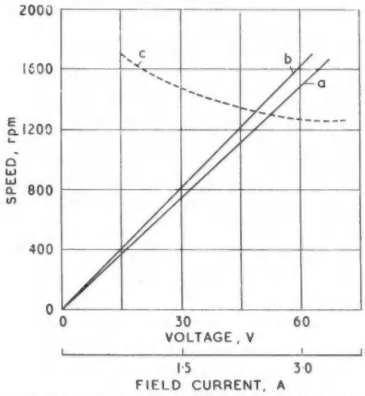

Fig. 4. No-load speed characteristics for single-phase operation, showing speed as a function of voltage with field currents of (a) 3 A, and (b) 2 A, and as a function of field current with (c) a voltage of 50 V.

provision for electrically shifting the interpoles, involving a great many mechanical and electrical complications, it may be possible to reduce the differences in temperature rise in various portions of the armature.

Operation as a Series and Compound Motor

By using current transformers and rectifiers, it should be possible to provide series excitation along the main poles proportional to line current. Also, it may be necessary to provide series excitation to the quadrature poles to improve power factor. It should also be possible to use an automatically controlled method of varying power factor and speed by the use of servo-mechanisms.

Conclusions

From the results of these investigations, it is concluded that this new type of machine has practically all the characteristics of a d.c. motor, in addition to the power-factor control characteristics of a synchronous motor. Also, it is a versatile machine, capable of being adapted to single-phase and polyphase systems, and, by automatic control it should be possible to get any desired characteristics for the motor. Furthermore, the d.c. field and motor drive power for rotating the brushes are small, while brush and commutator wear is negligible when the armature is rotated approximately at synchronous speed in the direction of rotation.

The problem of commutation and methods of improving it must be studied. Also, it would be better to provide a direct drive to the brush carriage by fitting trunnion bearings to the commutator end and making the brush drive motor as an overhang similar to alternator exciters. In addition, the stability of operating the brush drive motor must be increased by the use of dampers and salient poles, since any hunting in this motor would affect the operation of the main machine.

Finally, it is hoped that, even though tests have been conducted only on a small experimental machine, it should be possible to design larger-capacity machines having similar characteristics.

U.S.A.

Experimental Plasma Propulsion System

(From *Electronics*, Vol. 32, No. 31, July 31, 1959, pp. 86, 88, 89, 4 illustrations)

PLASMA propulsion utilizes the magnetic acceleration of a plasma to eject particles at a low-mass flow rate and high velocity, and hence to produce low thrust and high specific impulse.

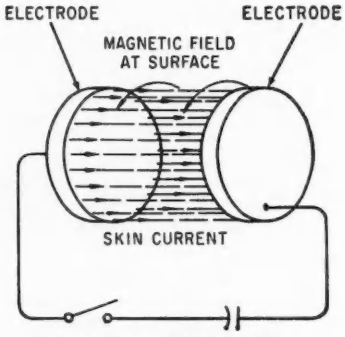

Fig. 1. Basic pinch-effect cylinder.

An experimental plasma propulsion system, using the pinch effect to obtain thrust, has been constructed and makes use of the principle of the basic pinch-effect cylinder shown in Fig. 1, in which a capacitor bank, with a range between 50 and 1000 μF, can be charged to from 1000 to 20,000 V. The capacitor is connected to the electrodes forming the ends of the cylinder through a switch and low-inductance, low-resistance conductors. When the switch is closed, a discharge is initiated in the gas in the form of a Townsend shower. As a result of the skin effect, current flows initially in a thin hollow cylinder of plasma confined to the outer edge of the confining cylinder. The magnetic forces resulting from the current cause the hollow cylinder to constrict towards the centre line of the cylinder.

The exact mechanism of this transition from Townsend shower to skin current is now under theoretical and experimental study. The force on a moving charged particle is proportional to the charge, velocity, and magnetic field, and is at right angles to both the velocity and the field. In this case, the field is self-induced by the current, and the direction of force on both the positively charged ions and negatively charged electrons is radially inwards. The gas is highly ionized by the high currents flowing and the consequent heating; currents as high as 500,000 A are used in the experiments.

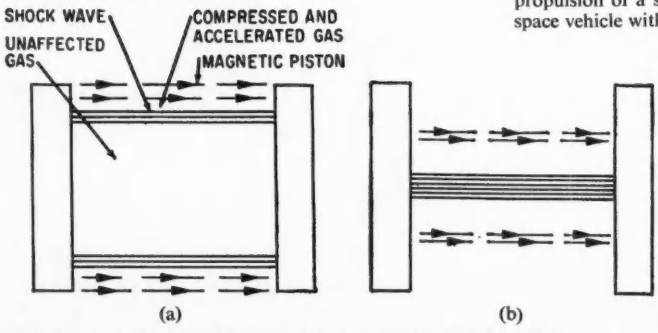

Fig. 2. Movement of the magnetic piston and shock wave in the pinch-effect cylinder.

The action is assumed to be like a magnetic piston in cylindrical form which is constricting radially inwards. Thus, the gas is also being driven radially inwards. This magnetic piston causes a shock wave to run ahead, raising gas pressure and temperature to very high values.

The pressure in this region opposes the constriction of the magnetic piston. In Fig. 2a, these conditions are shown at the initiation of discharge, the magnetic piston being near the outer radius. A shock wave runs radially inwards ahead of it and, between the piston and the shock wave, is a region of compressed and accelerated gas, while ahead of the shock wave is unaffected gas. Finally, as shown in Fig. 2b, the shock wave reaches the centre of the cylinder and the piston lags behind.

A cross-section of the curved electrodes used is shown in Fig. 3. After gas breakdown, a skin current flows, the pinch effect drives the gas towards the centre, and a shock wave is generated ahead of the piston. After initiation of the discharge, the conditions with this type of electrode are similar to those shown in Fig. 2a for the simple cylindrical electrode. However, a short time later, owing to the electrode curvature, the piston and the shock wave become forced into an axial direction, rather than continuing radially inwards. Finally, the magnetic piston reaches its furthest travel, and compressed and accelerated gases at a high velocity continue to flow axially and then leave the nozzle.

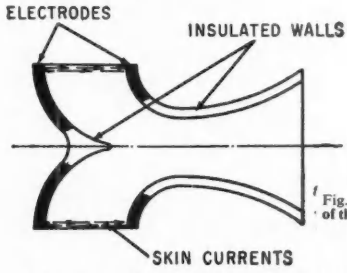

Fig. 3. Cross-section of the curved electrodes used.

The results obtained with the experimental equipment constructed have verified theoretical predictions, and a preliminary measurement of the thrust developed by this nozzle-electrode assembly has been made, the peak thrust obtained with a specific impulse of over 1700 sec being more than 4000 lb.

A plasma engine would be eminently suitable for the propulsion of a space vehicle and, in this connection, a space vehicle with a payload of 5000 lb has been studied for a mission starting in a geocentric orbit around the earth and terminating in an orbit around Mars. With a peak thrust developed by the engine of 9000 pounds per pulse, a pulse length of 0·39 microsecond, and a repetition rate of 500 pulses per second, an average thrust of 1·8 lb is developed. Assuming that the weight of the engine system, including a primary nuclear power reactor, is 12,000 lb, and that the overall weight of the space vehicle, including 8300 lb of propellant, is 27,300 lb, this mission would take just over eight months to accomplish.

matic production, as shown in Fig. 4. In this case, the machine is equipped to produce headed pins, 0·25 in. in diameter and 1½ in. in length. These components are ground on a fully automatic cycle of 800 finished components per hour at 100% efficiency. Stock removal is 0·004 in., and components are ground in one cut, holding a tolerance on finished size of 0·0003 in.

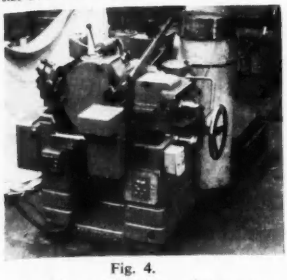

Fig. 4.

In this application, the components are loaded into a vibrating type of hopper and are fed onto loading rails which carry them in a single line, hanging head uppermost. At the lower end of the loading rails and at the front of the machine is located the automatic loading attachment, into which components are fed one at a time, controlled by an escapement mechanism. As each component is passed from the escapement to the loading Vee at the correct point in the cycle, the loading Vee is fed forward with a following pusher strip, which pushes the component from the Vee onto the workplate between the wheels. At this point the grinding-wheel head is automatically fed forwards to grind the workpiece. During the grinding time the loading Vee and pusher are retracted to receive the next component from the escapement. At the conclusion of the grinding cycle, the wheel-head automatically retracts, and the ground component is ejected. Immediately the ground component leaves the wheel, the loading Vee and pusher transfer the next component to the wheel area and the automatic cycle is repeated.

Heenan & Froude Limited

Among exhibits from Heenan & Froude Limited is an example of one of their " Multiform " machines, in this case the model S.1½, which is one of the latest additions to this range of automatic wire- and strip-forming machines.

The S.1½ Multiform is a streamlined, four-slide machine, occupying a floor space of only 12 × 5 ft, including the stock reel. It can be tooled to produce within close tolerances a practically unlimited variety of components ranging from extremely simple forms to intricate items, some of which, when manufactured by alternative methods, may require as many as ten separate pressing operations. Because of this ability to produce accurate components at high speeds and at low costs, the Multiform, although of comparatively recent introduction, has already achieved great popularity both in the U.K. and overseas.

Even when it is impossible to manufacture completely by the use of a Multiform, it is frequently economical to use the automatic machine to bring components to a stage where only one further operation is required. Tool manufacturing costs are often lower than those for making multiple or follow-on press tools, and appreciable savings in materials can frequently be made. An additional advantage is that a wide range of attachments, including positive blank clamps, ring setters, lock-seaming and hopper-feed devices, can be used to increase still further the inherent versatility of these machines.

All moving parts, including the tool area itself, are fully guarded, but are completely visible through the hinged perspex guard covers while the machine is in operation. Forming slides are cam-operated and are positively controlled in both directions, adjustment to slide timing being by rotation of the cams. A variable-speed drive through a belt transmission is standard, and an automatic declutching device, which throws out the clutch as soon as the guard covers are lifted or in the event of the strip buckling or feeding short, can be supplied, if desired.

Dowding & Doll Ltd.

In addition to a range of Dowding universal hobbing machines for the rapid production of accurate gears up to 8 in. in diameter, for small gears of the type used in the clock, meter, and instrument industries, and for the rapid generation of long splines, spur or helical gears up to 7 in. in diameter, and high-angle spirals, Dowding & Doll Ltd. are exhibiting the British Wiedemann turret punch press, model RA.41P, with which the piercing of components such as electrical and aircraft panels can be performed rapidly, accurately, and economically.

In this machine (Fig. 5), the apertures to be pierced are located from a master template by means of a high-speed pantograph and a depressible stylus. The templates themselves can be made on the machine, and standard tooling is used, mounted in rotatable turrets which can be provided with 16, 18, or 20 stations, enabling any tool set to be instantly indexed to the operating position. Since only the stylus enters the template and not the punches, all template holes are of ¼-in. diameter, irrespective of the size or shape of the apertures in the finished work. The template and the work are clamped on the machine, with their datum edges against fixed stops, so that they are in correct relationship, the template being clamped to the surface of the stationary table and the work-blank to a pantograph carrier which can be moved in relation to the punch centre-line by means of the stylus handle. As the stylus is moved from one template hole to the next, the work blank moves in relation to the punch. As soon as the stylus enters a hole in the template and is fully depressed, the press operates. Coloured lines are painted on the template to link all similar apertures in the work and, by following these routes, the number of turret and work movements is reduced to a minimum. Similarly, coloured tabs on the turret indicate when the appropriate punch is in the operating position.

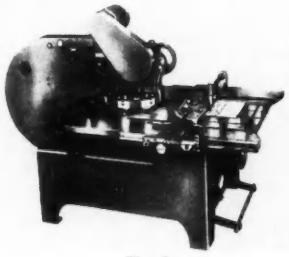

Fig. 5.

Rotation of the turrets is synchronized to ensure precise alignment of the tool set, which is positively located in the operating position. An interlock prevents accidental operation of the press between stations. Tools for louvres, transformer and instrument cut-outs, countersinks, knock-outs for conduits, as well as combination corner cropping tools and plunge tools, in addition to a range of circular tools and regular shapes, can be mounted in the same turret and are readily interchangeable.

Another Dowding & Doll exhibit is an example of the Ahcol " Rotamill " semi-automatic rotary machine, which has been developed for the rapid continuous milling of simple jobs, such as the production of slots, flats, and faces. This machine (Fig. 6) is easy to operate, and tooling is very simple. The parts to be milled are inserted into simple fixtures spaced around a continuously rotating work drum, clamping and unclamping being performed automatically, where practicable, as the components enter and leave the cutting zone. Alternatively, parts that are awkwardly shaped and difficult to hold can be clamped in simple fixtures mounted on the face-plate and the machine can be set to pro-

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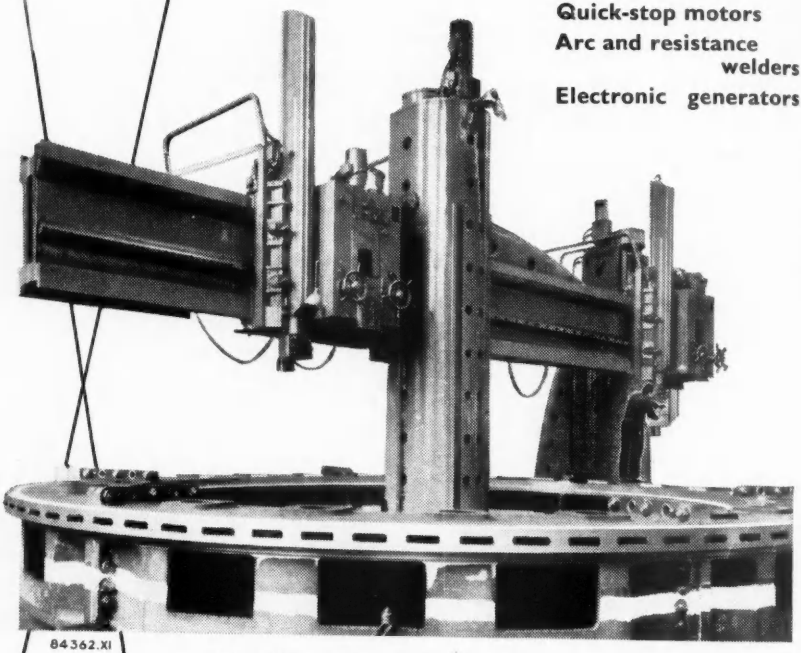

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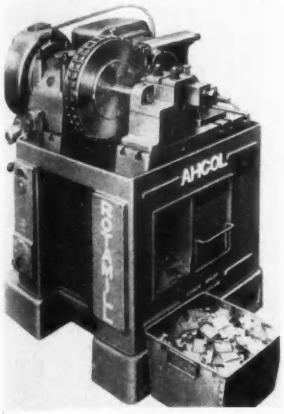

Fig. 6.

vide normal feeds while cutting with fast traverse between stations — a method which can also be used for small batches. In both cases milling proceeds while the parts are being loaded, and the milling process continues uninterrupted. The spindle is integral with the face-plate and machined from Meehanite. The standard work-drum is 12 in. in diameter, and cutters up to 6 in. in diameter can be used and can be ganged up to 6 in. in width, endwise adjustment being provided. The work-spindle can be moved towards or away from the cutter spindle, and a graduated collar on the leadscrew indicates increments of 0·001 in. Four cutter spindle speeds, i.e., 132, 211, 330, and 528 rpm are provided.

Still another Dowding & Doll exhibit is a new model of the " Accuratool " capstan and second-operation lathe, provided with fingertip control and designed for operation in the seated position.

Fig. 7.

The design of this machine (Fig. 7) has been carefully studied from the point of view of reducing operator fatigue to a minimum. Thus, ample leg room is provided, and a full-length rail can be used as a foot-rest. Also, the machine itself has been moved further forward on its bases, thereby bringing all controls nearer to the operator, who can work continuously in the seated position without fatigue. The machine itself is exceedingly versatile, by virtue of the extensive range of equipment available. Any required spindle speed can be selected instantly from an exceedingly practical range, and rapid spindle braking has also been incorporated, enabling savings of from 10 to 15% in actual production times to be achieved.

Centec Machine Tools Ltd.

An interesting exhibit is a multi-station rotary transfer machine, designed and manufactured by Centec Machine Tools Ltd., which is constructed of standard components and clearly demonstrates the simplicity, versatility, and economy of rotary-transfer production.

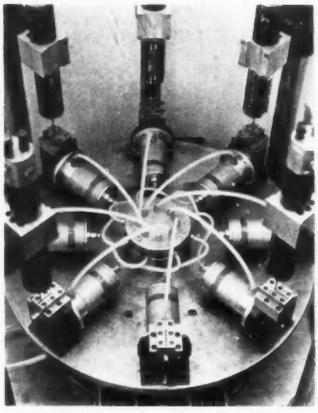

Fig. 8.

This machine, which incorporates air-operated cylinders and valves manufactured by **Maxam Power Ltd.** for the control and operation of the sequencing and clamping systems, is shown in operation, drilling automatically to fine tolerances seven holes of $\frac{1}{8}$-in. diameter at $\frac{3}{16}$-in. centre distance in a small brass component, the production rate being $7\frac{1}{2}$ seconds. The basic unit is a Centec rotary indexing table, 16 in. in diameter, which can be set to index any angle divisible by 3 up to 180 deg., and which has an accuracy of repetition for any position of $\pm 1{\cdot}5$ seconds, and an angular accuracy of ± 5 seconds. Speed of operation is controlled by a variable orifice of a hydraulic dashpot and by pneumatic flow restriction. A specially designed rotary valve sequences the release and clamping of the components at the pneumatic fixtures. Fig. 8 shows the arrangement of the drilling, positioning, and ejecting positions on the indexing table, and the layout of the Maxam $2\frac{1}{2}$-in. clamping cylinders and the pillar-supported power units for drilling.

Alfred Herbert Ltd.

Among the range of equipment featured by Alfred Herbert Ltd., a particularly interesting exhibit is one of their model 2D capstan lathes (Fig. 9) equipped with a simple programme-control system developed by the company. This system, which has already been described in a previous issue of this journal, automatically selects speed changes and start, reverse, and stop to the spindle as the turret is indexed. As a result, setting-up times, operational fatigue, and non-cutting times are reduced; the fundamental advantage of the system, however, is that it ensures that the operator uses the correct speed for a given operation, thus achieving greater efficiency from relatively unskilled labour, with work of better quality and longer runs between tool regrinds.

Basically, the system comprises a punched-plug panel and limit-switches. Thus, plugs inserted in the appropriate holes in the panel select the required forward or reverse direction of the spindle, spindle speed, spindle start and stop, and change of spindle rotation, when required for withdrawal of a tap or for such operations from the rear toolpost as parting-off. Automatic selection is actuated by modified " barrel-type " stops fitted to the end of the capstan slide contacting the limit switches. Thus, indexing of the turret at the end of the reverse traverse of the capstan slide automatically selects the preset conditions for machining from the next turret face. Change of spindle direction, e.g., after a tapping operation, is automatically controlled at the end of the stroke of the capstan slide.

A limit-switch is fitted to each face of the hexagon turret and, when contacted, selects the appropriate row of plugs on the board, thus controlling direction of rotation of the spindle, motor speed, and, through magnetic clutches in the two-speed driving box, spindle speed. The change of spindle rotation at the end of the cut is obtained by a stop bar contacting the dead stop and actuating a limit-switch through a lever arrangement. For programme control, a card can, if desired, be prepunched in the planning department and superimposed over the machine plug panel to ensure the correct insertion of the plugs.

The lathe is provided with a control panel which has a switch for automatic or hand control, so that it can be used as a conventional type of capstan lathe for bar work up to $1\frac{1}{2}$ in. in diameter and chuck work up to 9-in. swing. The machine

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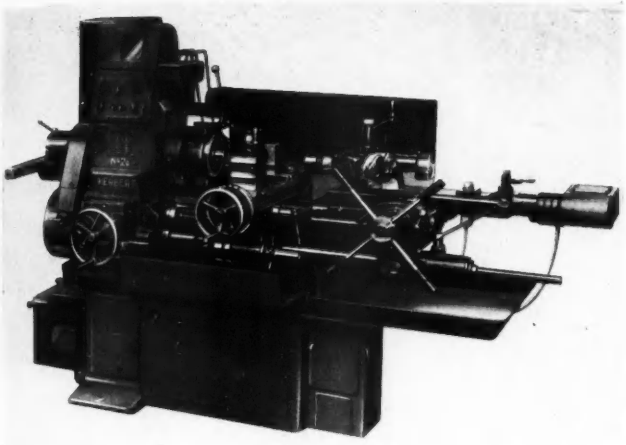

Fig. 9.

exhibited is equipped for bar work; consequently, it has been fitted with a bar-feeding arrangement with a mechanism for automatic opening and closing of an air-operated dead-length bar chuck.

Gendron Frères S.A.

In addition to conventional models from their wide manufacturing range, Gendron Frères S.A. (represented in the U.K. by **Stanley Howard Limited**) are showing in operation two grinding machines incorporating automatic work-loading and unloading systems, i.e., the type RA 16 grinding machine and the type ROPA 16 grinding machine.

The type RA 16 grinding machine (Fig. 10) is being shown grinding car gearbox shafts and, as this component incorporates a hole, it is positioned on a mandrel fitted to an endless chain. As can be seen from Fig. 10, each component on the endless chain eventually assumes a horizontal position, when it is placed on a work-rest which accurately positions it between centres by means of micro-switches. The footstock then pushes the part onto the workhead, where an expanding chuck initiates rotation of the workhead. The wheelhead then infeeds, starts grinding, and retracts, after which the part is unloaded from the chuck and is tipped over onto a discharge rack.

Grinding is effected on two different diameters of the component, involving the use of two grinding wheels mounted on the same sleeve. A safety device is provided to stop the loading mechanism during wheel-dressing, which is carried out by an automatic wheel-profiling unit operated by a counter which is adjustable between 1 and 170 components. As grinding is required to close limits, a self-sizing unit is fitted, this unit being automatically positioned during the grinding cycle.

The main feature of the automatic wheel-profiling attachment is that it is universal, i.e., it can dress a wheel to suit parts having cylindrical or tapered diameters or having straight faces. The unit is hydraulically powered, and the pressure of the feeler on the template is very low, thereby avoiding wear and distortion. With the exception of certain profiles incorporating very small radii, a standard commercial diamond, with an apex angle of not more than 70 deg. and a non-polygonal profile, can be used. The diamond holder traverses rapidly until it comes into contact with the wheel, and then traverses at the truing speed. If several wheels are mounted on the same sleeve, a rapid traverse is provided between each wheel. The return stroke is carried out at high speed with the diamond holder in an elevated position.

It should be noted that the automatic loading and unloading unit is entirely independent of the machine itself, except for electric and hydraulic feed lines. The endless-chain method used is also interesting, inasmuch as it is provided with a range of mandrels to suit from 35 to 50 components, according to their size.

The type ROPA 16 grinding machine (Fig. 11), also fitted with an automatic work-loading and unloading system, is shown grinding car gearbox pinions. In this case, the parts are chuck-ground and are therefore held in a hydraulically operated expanding chuck fitted to the workhead.

In operation, the part slides down a chute after having been positioned correctly. This chute brings the part in front of the loading mechanism, which grips it through its hole, and then positions it on the expanding chuck, which also holds the part through its hole. The cycle follows by an angular hydraulic infeed to the wheelhead for the machining operation. When grinding has been achieved, the wheelhead retracts and a fork-shaped unloading mechanism pushes the part towards a discharge rack. The next part then falls by gravity and is picked up by the loading mechanism, and the cycle is repeated. As before, the wheel is dressed by means of an automatic wheel-profiling attachment, operation being initiated by a counter which is adjustable between 1 and 170 parts, depending on the required profile. After the truing operation is completed, the safety device preventing the loading mechanism from functioning withdraws, and the machining cycle is renewed, without intervention on the part of the operator.

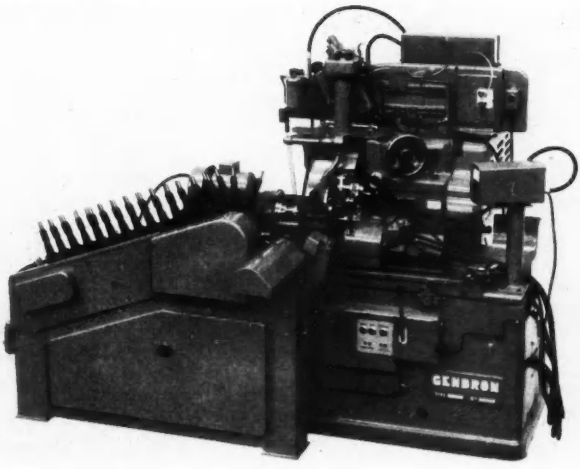

Fig. 10.

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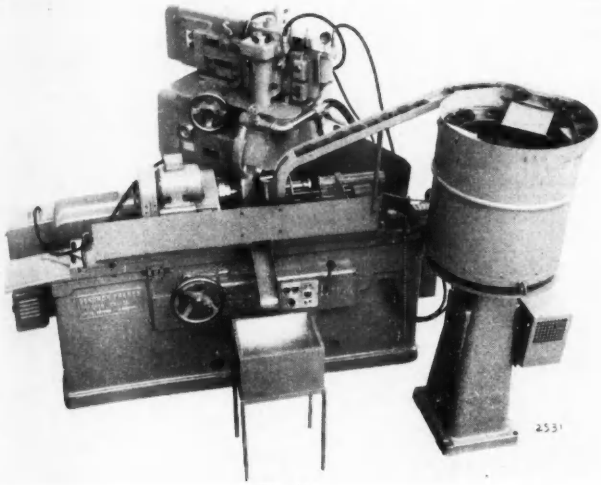

Fig. 11.

It should be noted that the chute fitted to this machine is long enough to ensure from 20 to 25 minutes of operation, thus giving considerable latitude to the operator to feed a number of machines at the same time.

The Cincinnati Shaper Company Ltd.

Exhibits from the Cincinnati Shaper Company Ltd. include a guillotine shear and a press brake, both in actual operation. The guillotine shear, ¼ in. × 10 ft, operates at 60 strokes per minute with consistent accuracy and is equipped with a magnetic sheet support, which maintains accuracy when shearing light sheet up to 16-gauge, as it ensures that the sheet is held horizontal through to the back-gauge. Front control of the power-operated back-gauge is provided. This is a standard feature of all Cincinnatti shears and permits precise setting of the gauge from the normal operating position. Also, a direct-reading indicator is conveniently located at the front of the machine.

The 250-ton Cincinnati press brake (Fig. 12), 126 in. between housings, incorporates steel interlocked construction with centre-line loading, deep bed and rams, and a tilting ram adjustment. In addition, it includes a new automatic cycling system which provides for two speeds for each working stroke of the ram. The downward stroke is made at a high speed to a point just above the work, and the ram then continues at a slow speed to bottom dead centre, after which it returns to the top of the stroke at a high speed. In this way, danger from "whip-up" and spoilage through "back-bends" is eliminated, while it has been found in practice that any need for slipping the clutch is obviated when the press brake is equipped with this automatic cycling system.

E.M.I. Electronics Ltd.

Some of their latest electronic machine-tool control systems are being featured by E.M.I. Electronics Ltd., including control equipment for two- and three-dimensional contour-milling machines, of a type which is now being fitted to a wide variety of machine tools manufactured by British, European, and American companies.

An example of E.M.I. positioning systems is also being demonstrated, a new low-cost co-ordinate drilling table being of special interest. This table has co-ordinates of 10 × 10 in., with provision for automatic feed of the drilling head. In addition, the linear and rotary Inductosyn elements, which are the key to the accuracy of the E.M.I. measuring system and which are now being manufactured in the U.K. by the company, are being exhibited.

Other exhibits from E.M.I. include a number of examples of their industrial instruments, including the CS3 dynamic balancing machine, which can detect bearing displacements as fine as 0·000025 in. in rotors weighing up to 150 lb.

Stabilimenti di S. Eustacchio, S.p.A.

Exhibits from Stabilimenti S. Eustacchio S.p.A. comprise two roll lathes from a new standardized series consisting of five types, i.e., type A for heavy-duty roughing operations, type B for medium-duty roughing and finishing operations, type C for combined turning and grooving operations, type D for grooving operations, with a fixed bed, and type E for grooving operations, with a movable bed.

The two roll lathes exhibited from this series are types C and D. Of these, type D, intended for grooving operations, has a centre-height of 14 in. and is provided with eight speeds, mechanically changed, and a centralized manual control. The carriage is rigidly clamped to the bed and is equipped with a box-section tool-holder, with hand adjustment for cutting tools.

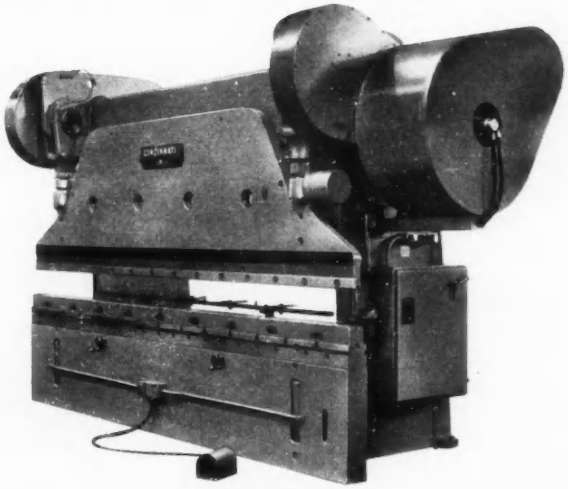

Fig. 12.

The type C lathe (Fig. 13), intended for combined turning and grooving operations, has a centre height of 20 in. and is fitted with a copying attachment. The headstock is provided with 16 speeds, speed

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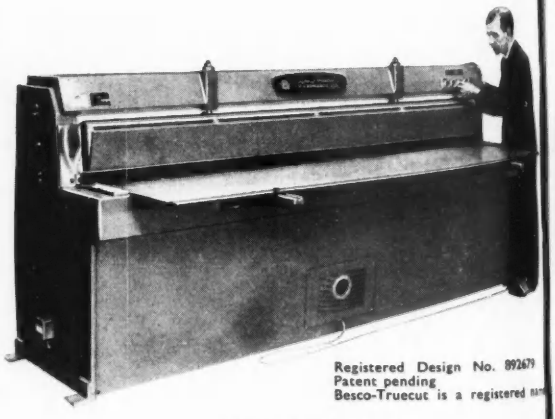

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changes being effected by means of a centralized manual control, though, if desired, a P.I.V.-type infinitely variable speed changer can be fitted. The carriage is a self-contained unit, driven independently of the headstock by its own d.c. motor, using magnetic amplifiers and providing infinitely variable feeds. Dial controls render selection of speeds and feeds easy and instantaneous, while directional controls simplify operation and prevent the possibility of errors.

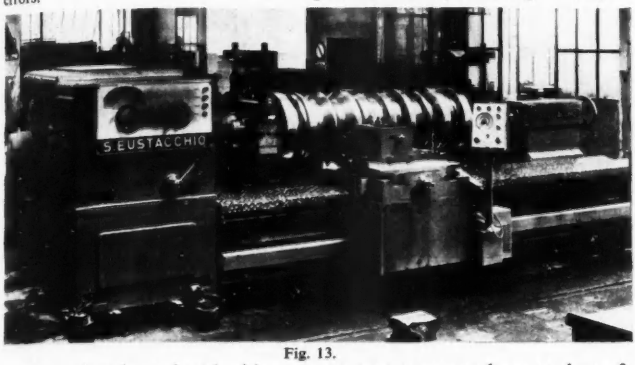


Fig. 13.

The carriage is equipped with a copying attachment which is controlled by electromagnetic clutches. This attachment, manufactured in co-operation with the Austrian firm of **Heid**, ensures a high degree of accuracy and absolutely safe operation; furthermore, as it is of very simple design, no special maintenance is required. If desired, the carriage can be used for normal turning operations, without the copying attachment, merely by turning a switch.

Edouard Dubied & Co. Ltd.

The exhibits featured by Edouard Dubied & Co. Ltd., who are well known as manufacturers of high-precision copying lathes, have clearly been arranged with a view to meeting the demand for automation. Thus, their No. 517 fully automatic lathe is not only suitable for mass-production purposes, but also for medium-sized batches, while automatic production lines can readily be formed with the use of Dubied conveyor units.

Such a production line, formed with two No. 517 fully automatic lathes, is demonstrated in connection with the machining of shafts of electric motors in two operations. Three selected tool feeds of 0·00473, 0·00866, and 0·01417 inch per revolution ensure the surface finish required, while the automatic measuring and tool-readjustment attachments incorporated check each component being turned, adjust the tools, where necessary, and switch off the lathe should the diameter be outside the prescribed tolerance. The setting-up time for this lathe with its loading device requires only 30 minutes approximately.

Another Dubied exhibit is a hand-loaded No. 517 automatic lathe with an automatic recycling attachment. This lathe, with its automatic feed control, comprising three adjustable working feeds and one rapid feed, is eminently suitable for turning batches of from 10 to 20 parts or more, enabling a single operator to control a number of these machines at the same time. This lathe is shown in action turning chrome-molybdenum steel gears in a single operation, the total machining time, including automatic plunge-cuts, being 151 seconds. This lathe is equipped with an automatic swivelling twin-tool holder, equipped with roughing and finishing tools which, engaged successively and automatically in accordance with a preselected programme, offer the advantage of improved surface finish, the maintenance of closer tolerances, and the elimination of secondary operations.

The smaller, but equally efficient, Dubied No. 514 hydraulic copying lathe is also being demonstrated, in this case in connection with the internal and external turning of a tapered aluminium tool-holder. This fairly complicated workpiece, machined at spindle speeds of 4000 and 2800 rpm, requires an overall time of only 110 sec, including a finished tolerance of 0·001 in. on the internal bearing seat. The No. 514 lathe, which is equipped with an automatic two-feed control system, is especially economical for turning batches of ten or more components.

The Newall Engineering Co. Ltd.

In addition to their "Spacematic" 1520 automatic-positioning jig-boring and milling machine, equipped with the **Airmec** "Autoset" measuring and control system, as described in the special supplement on *The Numerical Control of Machine Tools* accompanying this issue, The Newall Engineering Co. Ltd. are showing their standard model HAC crankpin-grinding machine tooled for the pin-grinding of four-cylinder shafts.

This machine (Fig. 14) is designed for the rapid production and high-grade micro-finish of pin diameters and is the smallest in the Newall programme, with a 16-in. swing and a capacity between work-spindle faces of 48 in. Traverse speeds of the table are infinitely variable between 3 and 160 ipm by hydraulic power. A control unit, which slightly elevates the table by means of oil pressure, facilitates positive swivel adjustment for taper correction, ensuring the parallelism of the pins being ground.

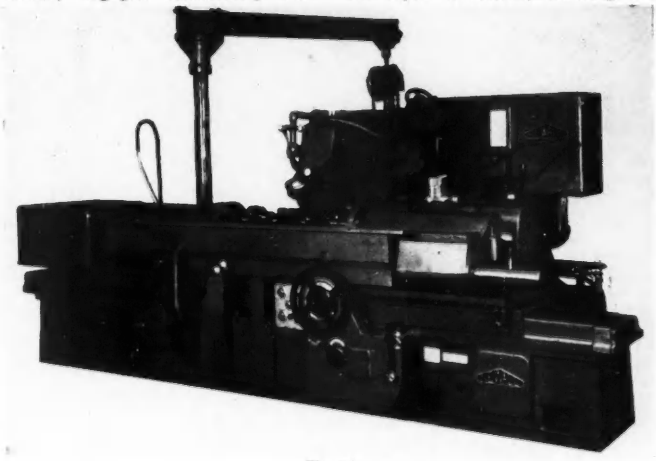
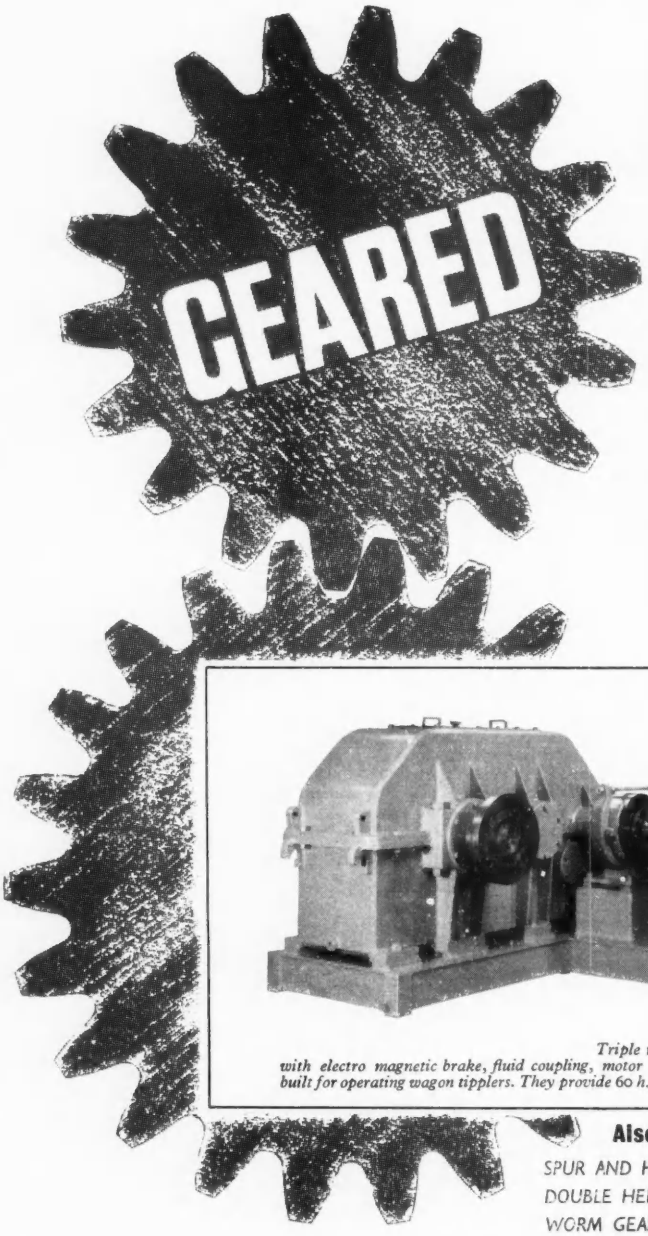


Fig. 14.

The spacing bar and plunger, used for rapid and precise alignment of crankpins with the grinding wheel, are hydraulically operated. The interchangeable and adjustable spac-



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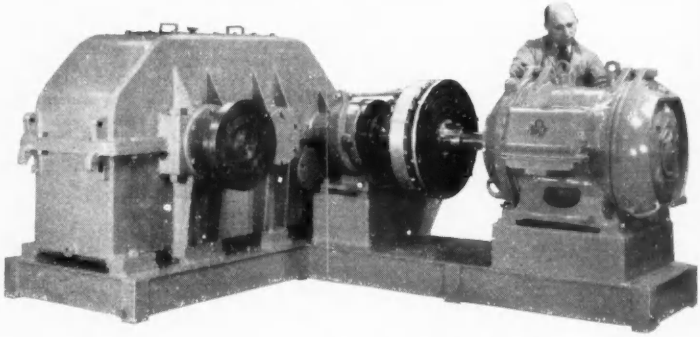

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ing bar is attached to the front of the table for ease of change-over when a variety of shafts is to be ground. The wheelhead is provided with a 5-in. rapid approach and withdrawal movement, together with four automatic variable infeeds, one for face-grinding and three for diameter-grinding, the latter giving, in effect, a diminishing feed. Both heavy-duty work-heads are rotated by a common large-diameter shaft. An "Etamic" two-stage size-control unit, which ensures correct determination of finish diameter and governs the automatic cycle of the wheelhead, is fitted, and is illustrative of a variety of size-control systems that can be provided to suit the user's preference.

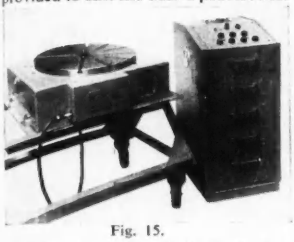


Fig. 15.

Other Newall exhibits include a range of optical rotary indexing tables and the O.M.T. automatic indexing 30-in. rotary table, which has been developed for high-accuracy automatic rotary indexing and is equipped with the E.M.I. electronic positioning system (Fig. 15). The basic measuring element employed is an Inductosyn of 12 in. diameter, which gives a setting accuracy of ± 3 seconds of arc, repeatable to ± 1 second, the traverse speed of the platen being 2½ rpm. The E.M.I. equipment is available in two forms, i.e., with manual setting dials or with tape control additional to the setting knobs. The use of tape controls enables any number of settings to be automatically programmed and provides facilities, in the form of contacts, to control the head motion of the machine in use; as a result, a fully automatic cycle is introduced for producing a number of holes of the same size.

C.V.A. Jigs, Moulds & Tools Ltd.

In addition to a wide range of their CVA automatic screw machines, CVA dieing presses, and CVA six-spindle turret drilling, tapping, and boring machines, and the CVA-Kearney & Trecker 415 TF vertical milling machine with Ferranti numerical control, C.V.A. Jigs, Moulds & Tools Ltd. (whose distributors are **E. H. Jones (Machine Tools) Limited**) are exhibiting a CVA-Lodge & Shipley "Powerturn" 90-deg. Copymatic lathe, this being the latest addition to the "Powerturn" range of lathes manufactured by the company under a licensing agreement with Lodge & Shipley in the U.S.A. Three models are available, i.e., 13, 16, and 20 in., with 30, 54, 78, 102, or 125 in. between centres in either toolmaker or engine types. The machine exhibited is the No. 2013 16 × 78 in. toolmaker lathe, which is shown carrying out internal and external spherical turning operations from flat templates.

Of particular interest in the field of automatic screw machines is the CVA No. 8 (Fig. 16), which is exhibited equipped with a new skip-indexing attachment, cross-drilling in conjunction with a two-speed brake unit and a vertical slide, and the new constant-throw turret, which provides increased usable feed travel of the turret slide, increased overall length capacity, greater work clearance on indexing, and a harmonic, shockless indexing action.

The essential feature of the constant-throw turret is that the turret return-spring acts directly against the rack instead of the turret slide. Throughout the indexing movement the cam lever roller is held in contact with the cam by the action of the return-spring against the rack, resulting in the turret slide being smartly withdrawn for the full crank-throw distance, with no lifting of the cam lever. The entire indexing movement is this truly harmonic and the major cause of turret bounce and shock is eliminated. The need for a cushioning device is therefore eliminated, and, in turn, obviates the sluggish turret withdrawal that often

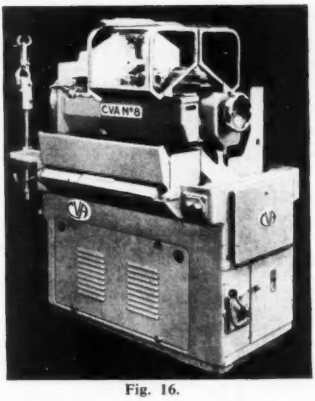


Fig. 16.

causes tool interference on the conventional turret. Finally, the absence of a cushion and the relationship between the rack and the return-spring allow full withdrawal to take place, even when the turret is indexed at its rearmost working position. A spring device interposed between the rack and turret slide ensures that any backlash in the mating members is taken up before turret tools begin to cut.

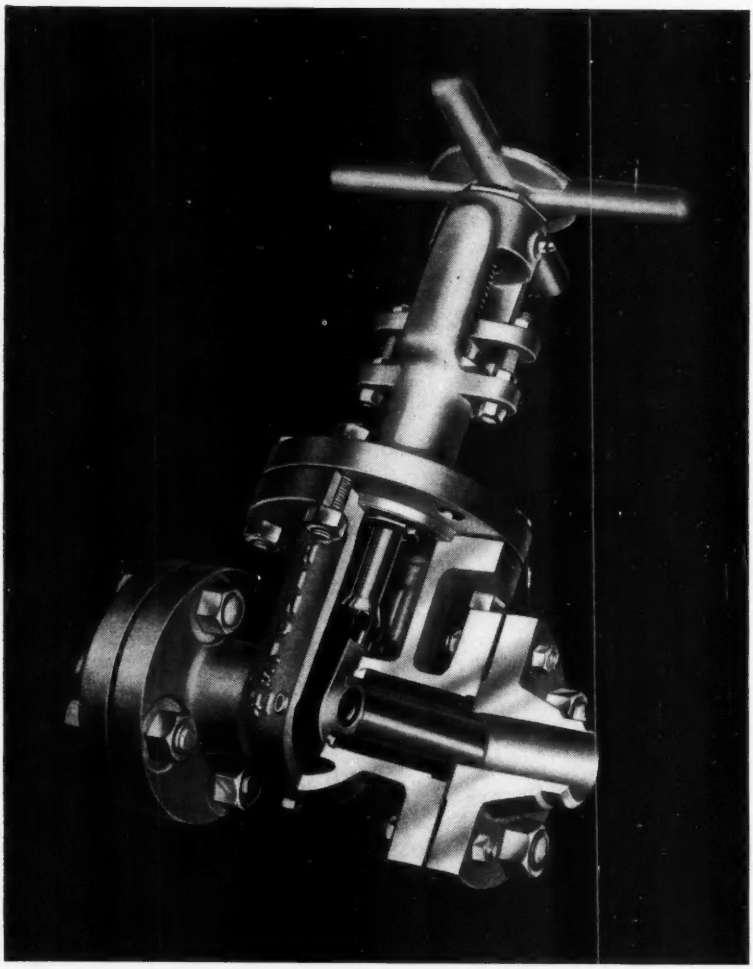
To take full advantage of the new turret features, ample screw adjustment is furnished for setting the distance between the collet face and the turret: on the standard short-throw No. 8 model, an additional ⅜-in. backward adjustment has been provided, compared with the earlier machine. The extra indexing clearance now available allows the full cam movement of 1⅜ in. to be used for cutting operations.

Another interesting characteristic of the constant-throw turret is the improved mechanical action of the indexing movement in relation to the operation of the one-revolution indexing clutch on the backshaft. Clutches of this type are very sensitive to load, since the final disengagement is influenced by the inertia of the revolving parts. With the conventional turret, the behaviour of the indexing clutch tends to vary according to the position of the turret slide when indexing takes place, and this can result in variations in component lengths machined from the turret. With the constant-throw turret, however, this condition does not arise, since the turret spring acts against the rack and not against the turret slide; the turret spring therefore exerts no load on the operation of the indexing clutch, ensuring uniformity of operation.

Rockwell Machine Tool Co. Ltd.

Exhibits by the Rockwell Machine Tool Co. Ltd. include an example of a British-built "U.S." Multi-Slide machine, in this case the Model No. 28, which is being shown producing high-quality stainless-steel blade clips, as used on a well-known make of windscreen-wiper assembly, at a rate of 120 components per minute.

This British-built "U.S." Multi-Slide is an automatic machine (Fig. 17), specifically designed for the economical production of stampings from coiled material. The machine is uncomplicated in operation, and the flow of power is smooth because the operations are timed to distribute the load throughout the cycle. The machine features a symmetrical layout of the slide arrangement, hardened slide-ways with hand-scraped Meehanite slides, a driving-shaft system surrounding the machine, ensuring proper distribution of the power and smooth operation, and hardened and ground cams. The standard equipment consists of one die-head with cam, four forming slides with cams, a vertical stripper mechanism, a flat-stock straightener, a special feeding unit, a stock check, a brake coupled with a monitoring device, and an automatic lubricating system. Up to two die-heads can be used on the No. 28 Model and up to four die-heads on the No. 35 Model, which is being exhibited untooled.



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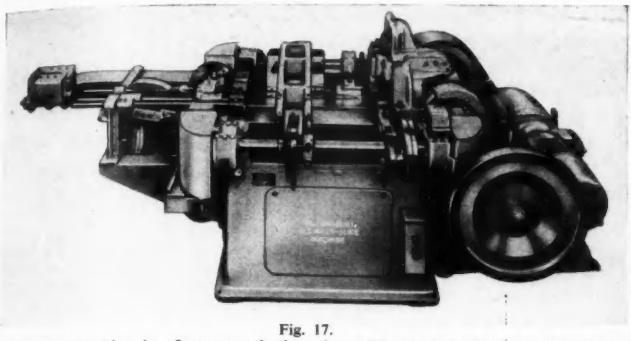


Fig. 17.

since the machine is of symmetrical design, it is possible for the die-heads to be mounted either from the front or from the rear—a useful feature, since the direction of sharp edges can be controlled.

A large number of other standard accessories is available, including such items as front and rear cut-off slides, rear auxiliary slides, positive blankholders, etc. Front cut-off slides are normally used for a straight cut-off, and rear cut-off slides for shaped cut-offs. The rear cut-off slide also has the advantage that it can be brought into very close proximity to the form post. A rear auxiliary slide used in conjunction with a die-head can be used as a double-acting press. Toggle presses (35 and 100 tons respectively) are available for both sizes of machine, and heavy-duty die-heads are available for the No. 35 machine.

In addition to these Multi-Slide machines, the company is showing a power-operated straightening machine for coiled material. This machine is specially designed to remove coil-set and incorporates a set of feed-in and a set of feed-out rollers, both of which are power-driven. The actual straightening rollers are idling and the top rollers are individually adjustable.

The drive is taken from a motor through a gearbox and a variable-speed control; in addition, a mercury control arm is fitted, with which it is possible to control the correct flow of the material required by the press. The actual model shown is the RS. 109, which has a capacity of 10 in. wide and up to 0·080 in. thick. Smaller and larger models are available.

Also on show is a new type of coil cradle for uncoiling material. This machine incorporates many novel features, including the loading of coils by rolling them into position, using a ramp or an overhead crane. The alignment of the coil in relation to the press is carried out by two individually adjustable inner plates. Four of the five rollers on which the coil rests are power-driven and synchronized with the draw-off mechanism. The design of the cradle enables the machine to be placed immediately beside the press, thus saving space. The cradle can handle strip up to 9 in. wide and up to a weight of 1500 lb.

Taylor, Taylor & Hobson

As is only to be expected, a wide range of measuring instruments and machine tools is being exhibited by Taylor, Taylor & Hobson, including cutter measuring microscopes, blade-edge microscopes, workshop microscopes, side-action or axial gauge-heads, high-magnification gauges, and micro-alignment telescopes.

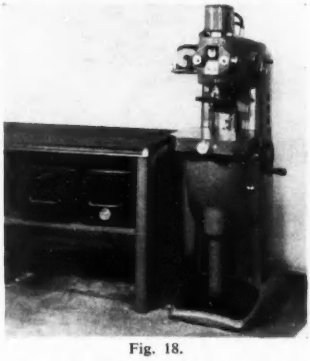


Fig. 18.

Machine tools include the JR router-copier, a compact 1:1 copying, profiling, routing, and milling machine, which produces a faithful, positive two-dimensional copy of the master, and a new rationalized engraving machine, which is a development of the well-known Taylor-Hobson CXL type, with a pantograph scale from 1:1 to 16:1. This new design simplifies operation and closely groups all controls, operation being simple and sensitive. Also exhibited is the JH engraver/miller, a heavy-duty, compact pantograph-controlled engraving machine, combining accuracy and ease of operation with rigidity and a large area of coverage. Pantograph reduction ratios are from 1:1 to 50:1, and a forming attachment permits precision engraving on curved or moderately contoured work.

Other exhibits include examples from the range of "Talysurf" instruments for providing surface-finish measurements on such components as ball and roller races, shafts, bearings, slideways, cams, and gear teeth; the "Talyvel" electronic level, in which the usual bubble is replaced by a pendulum with transducers which provide an electrical displacement signal; the type "B" auto-collimator for measuring errors of squareness, straightness, parallelism, truth, or angles between surfaces; and the Model 50 "Talyrond", which is designed to provide roundness measurements on such components as ball and roller races. This instrument (Fig. 18), which is fitted with a new table, has a range of magnification extending from ×50 to ×10,000, and measures accurately to within 0·1 micron. Means are provided for filtering out either surface irregularities or general errors in shape, so as to permit a close analysis of faults to be made.

W. J. Meddings Limited

Among the wide range of machines and equipment exhibited by W. J. Meddings Limited, including air-hydraulic unit drill-heads, hydraulic feed units for attachment to drilling machines, special-purpose drilling and tapping equipment, and a progressive drilling unit which has now been considerably modified and improved, a particularly interesting exhibit is their new Series 1 air-hydraulic unit drilling head (Fig. 19).

This small unit has spindle speeds up to 10,000 rpm, and an infinitely variable feed with any desired amount of rapid approach up to 1 in., the total stroke of the spindle being 1·25 in. Approach and retraction are extremely fast, i.e., 12 ips, and the output thrust of the drill spindle is 100 lb. The unit,

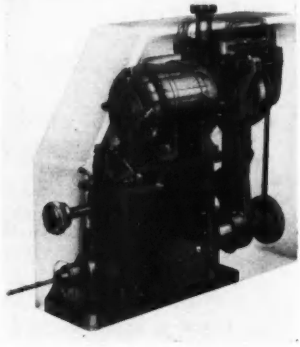
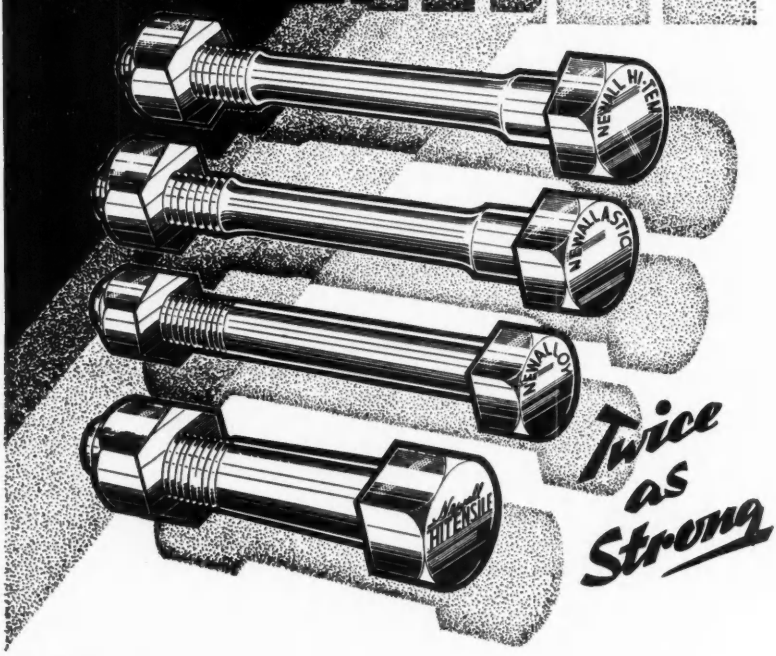


Fig. 19.

which is extremely compact, being only 4 in. in width, incorporates a completely isolated air and oil system.

NEWALL



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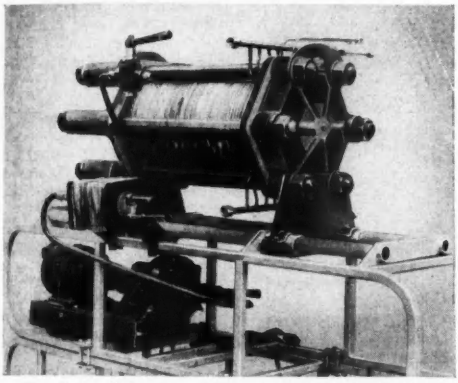
British Industrial Developments

The Hydrogen-Oxygen Fuel-Cell

Fuel-cells are by no means new; indeed, considerable research and development have been under way in various countries, notably in England, Holland, and the U.S.A., with a view to improving their performance and to devising alternative types, i.e., low- and medium-temperature types and high-temperature types, as described in our issue of June 1959. It is only now, however, that the first public demonstration has been staged of the hydrogen-oxygen fuel-cell of F. T. Bacon, the original inventor of the first practical fuel-cell. In this connection, it should be noted that ten years of original research was carried out at Cambridge University under the auspices of the Electrical Research Association and the Ministry of Power, before the National Research Development Corporation placed a development contract with Marshall of Cambridge Electronics Ltd. in 1957.



The fuel-cell battery demonstrated at Cambridge is made up of 40 cells, each 10 in. in diameter, and gives an output of 5 kW at 24 V under maximum load conditions. Each unit cell consists of two electrodes, one for hydrogen and the other for oxygen, separated by an electrolyte of strong potassium hydroxide. The electrodes are made of porous sintered nickel, with a thin layer of a smaller pore size on the liquid side, the oxygen electrode being treated with lithium and pre-oxidized to prevent corrosion. The electrolyte soaks into the sintered metal but, on the application of the gas under pressure from the back of the plate, is expelled from the larger pores; as the gas cannot bubble through the smaller-pored surface, owing to the surface tension of the liquid, there is a very large surface (about 40 m^2) of wetted sintered metal in contact with gas in each electrode.

Oxygen molecules on the positive electrode combine with water to form negatively charged hydroxyl ions, which each remove an electron from the oxygen electrode. The hydroxyl ions migrate through the electrolyte to the negative electrode, where they combine with the hydrogen to form water, depositing an electron in the process. Thus, the hydrogen electrode becomes negatively charged with respect to the oxygen electrode, and a current flows in the external circuit. In order to remove the water formed, the hydrogen is circulated past the back of the hydrogen electrodes, and the mixture of hydrogen and steam is cooled externally, so that the condensate can be released as required. The operating conditions of the cell are about 200°C and between 300 and 600 psi.

Bearing in mind the amount of development work already carried out on this particular cell and the improvements in fuel-cells in general reported by investigators in various parts of the world, the demonstration at Cambridge was frankly disappointing, particularly insofar as the manifest crudity of the demonstration unit and the enormous size of the complex control unit (not shown in the illustration) are concerned. It is true that this development work and its present rather unsatisfactory stage may have been hampered by lack of funds and this, in itself, is one more unfortunate example of how yet another outstanding British invention has been held back by national apathy and has been allowed to be exploited elsewhere. However that may be, it is none the less lamentable that, only at this late juncture, has Mr. Bacon's remarkable achievement received so much publicity, with the usual irresponsible nonsense and extravagant claims on the part of the daily press, all of which may serve to impress the man in the street but are more likely to arouse derision from the many technical men who already know something of the principles of the fuel-cell. Had this publicity been released some years ago, Mr. Bacon's fuel-cell would undoubtedly have received the universal acclaim it deserves as a truly important invention, and a far greater impetus would have been given to its subsequent development.

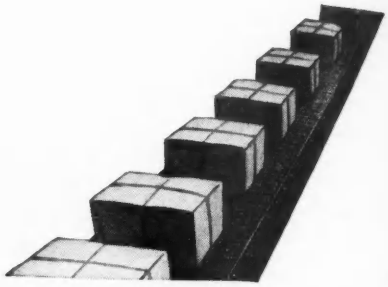
Production Line for Tractor Parts

A new production line, 150 ft in length, which is fed at one end with metal pieces and at the other end discharges tractor parts hardened, cleaned, and tempered, has recently been installed in the Glasgow works of the Caterpillar Tractor Co. Ltd. The hardening furnace, the quench tanks, and quenching mechanism, and the associated conveyor line were all designed and supplied by the Electric Resistance Furnace Co. Ltd., of Weybridge, Surrey.

The metal parts travel through the complete process in two lanes on a driven roller conveyor. After being cut to size, they enter an Efco roller hearth-furnace, where they are heated to 870°C. As they leave the furnace, parts to be water-quenched pass through water sprays. Parts to be oil-quenched are automatically collected in batches in the furnace and are then hurried along the line to an oil-quenching station. After the hardening process, the parts move into an Efco wash-booth, where all traces of oil are removed before they enter heating inductors to be tempered. The parts are finally cooled by a water spray before reaching the discharge end of the line. The progress of the parts along the line is interrupted by some of the operations, including the oil-quenching process. To maintain the maximum rate of production, the roller conveyor is arranged in sections, each with its own independent drive, and sections can be speeded to hurry the parts, as necessary, from one operation to the next. The overall conveyor speed is variable between 1 and 5 fpm, but, after the delay caused by the cutting operation, the parts move to the furnace at speeds up to 15 fpm.

The roller hearth furnace has a heated chamber, 50 ft long, 3 ft wide, and 2 ft high, heated by nickel-chrome elements mounted in the roof, the side walls, and under the hearth. The elements are all of substantial section to ensure a long working life and are mounted away from the brickwork to give maximum heat dissipation. They are arranged in four independently controlled zones, those in the final zone being positioned to compensate for heat losses through the door. Fully insulated and counterbalanced doors are provided at both ends, the exit door being made of heat-resisting alloy and water-

LIFT WITHOUT SLIP



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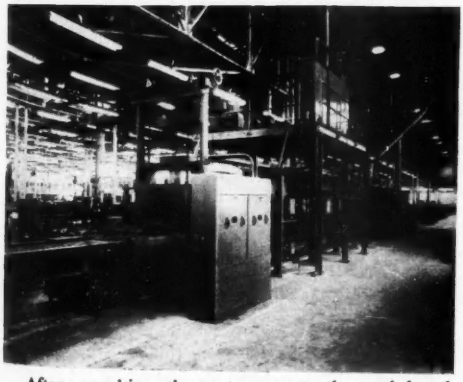
cooled. The rollers throughout the furnace are made of heat-resisting steel, and provision is incorporated for turning them by hand in the event of a power failure. Temperatures in the first three zones of the furnace are controlled by indicating instruments, and in the fourth by a strip-chart temperature recorder. All four zones are protected from overheating by instruments which give audible warning if they come into operation. The ancillary electrical equipment, with the exception of the temperature-control gear, is conveniently housed above the furnace on a platform erected for this purpose.

Immediately beyond the furnace is the water-quench station, where eight jets, together delivering 400 gallons of water a minute at a pressure of 80 psi, are directed onto the tractor parts. The water is pumped from, and returns to, a tank mounted on the floor beneath the conveyor. The tank is fitted with baffle-plates designed to trap scale and with a chute for scale removal, all internal metal parts being treated to resist corrosion. The temperature of the quenching water is controlled automatically by a temperature-indicating instrument which operates a valve in a water supply line. The water-quenching station is covered to the full width of the conveyor with a metal hood. Throughout the water-quench area, the rollers of the conveyor are of hardened stainless steel and have sealed bearings to keep out water and water scale. Adjustable guide-bars mounted on the conveyor supports ensure that the parts are properly aligned to pass through the quenching jets.

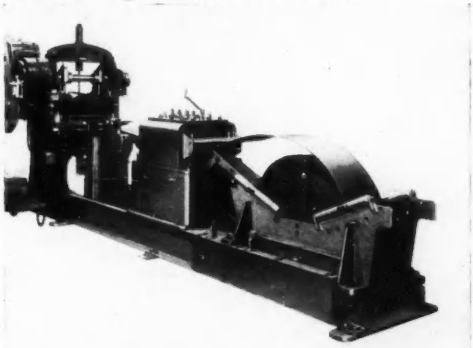
Parts to be oil-quenched are subjected to an automatic quenching sequence initiated by photoelectric-cell devices installed within the furnace chamber, several cells being used to cope with the range of part sizes being processed. The sequence starts with the retarding of the parts inside the furnace until a suitable batch has been assembled. The batch is then hurried from the furnace to the oil-quenching position beyond the water-quench station at a speed of up to 140 fpm. At the oil-quenching position a section of the roller conveyor serves as a quench table, which awaits its full load and then descends into an oil-quench tank, keeping the parts immersed for a preset time. When the parts are raised from the quench tank, they are again hurried forward to catch up with the batch ahead. The oil-quench tank, 10 ft long, 6 ft wide, and 2 ft 9 in. high, is fitted with oil filters and a mesh basket for the collection and removal of scale. The oil is fed by a circulating pump at a rate of 350 to 400 gpm through a multitude of nozzles so designed and positioned as to direct the flow of oil up over the parts being quenched. Like the water-quench station, the oil-quenching position is covered with a full-width metal hood.



After quenching, the parts move to the wash-booth, where they are sprayed first with an alkaline solution to remove oil, and then with hot water. The spray jets are carefully positioned to ensure that all surfaces of the parts are cleaned. The rinsing water is steam-heated and its temperature automatically controlled. The section of the conveyor is also fitted with stainless-steel rollers. From the wash-booth the parts are carried to induction coils fed from high-frequency generators, remaining stationary in the coils during the heating for tempering, and then cooled by passing beneath overhead water sprays. Some 6000 lb of tractor parts are discharged from the production line every hour.

Automatic Production Lines for Coiled Materials

A new range of automatic production machines for decoiling, straightening, and accurately cutting to length all sections of materials from coils of up to 36 in. in width is announced by Press Equipment Ltd., of Birmingham 19. Any length can be measured and sheared, though the normal range is between 6 in. and 72 in.

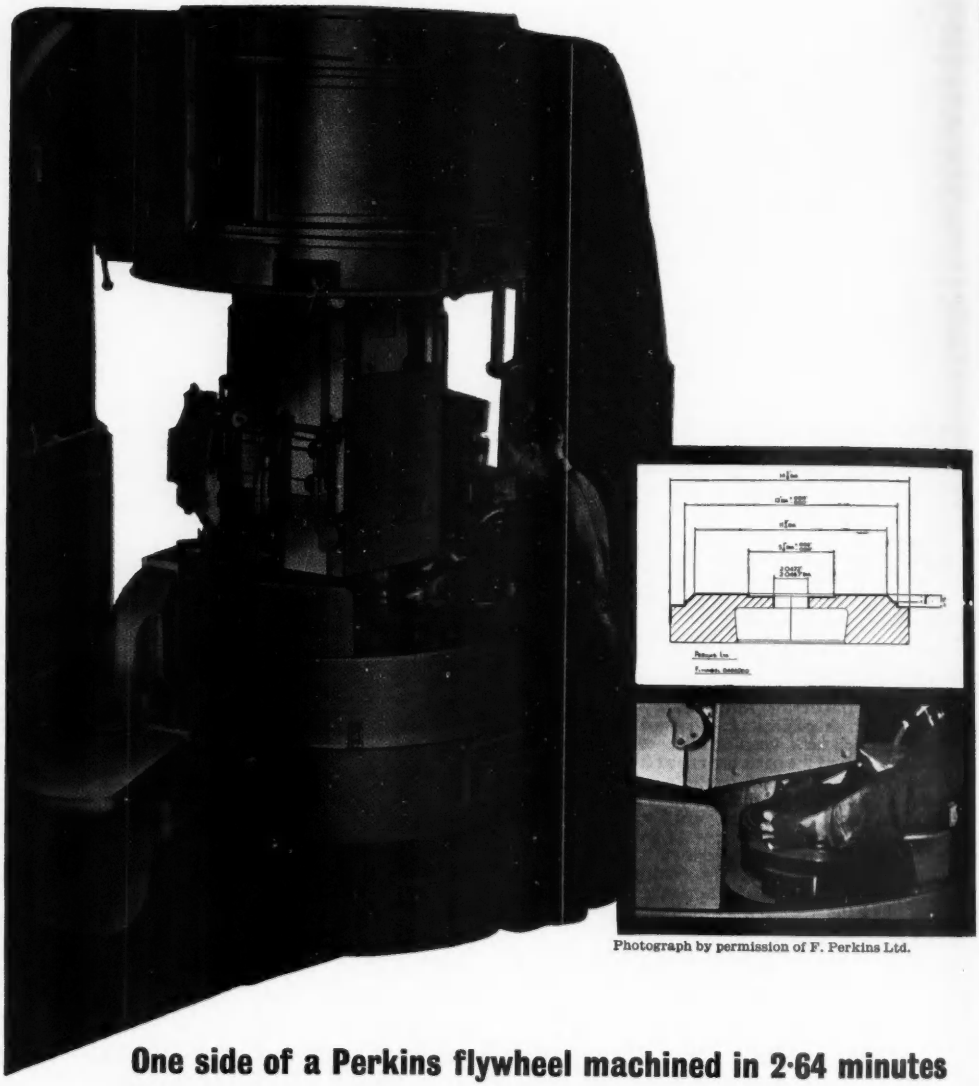


The coil cradle is power-driven from the straightener transmission to ensure synchronization, and the side plates and rollers are adjustable for coil width. The straightening and feeding head is driven from a self-contained motor through an electromagnetic clutch and speed variator, with a worm-and-wheel reduction gear. Pinch rolls and straightening rolls are adjusted by a crank-handle for material gauge and straightening pressure, and roll parallelism is achieved by the use of triple gears and twin pressure screws at each adjustment point. Handwheel control is provided to set the speed of the cut-to-length line to coincide with any following operation on the strip lengths and, if required, the machine performng this operation can govern the whole line. The material is measured and held until sheared, when it is released to fall onto a gravity or powered conveyor to the next operation. In place of a coil cradle, coil reels can be employed for holding thin-gauge or non-ferrous materials. The type of shear used depends upon the application, and existing shears can be built into the line.

Buried-Type Distribution Transformers

Although buried-type distribution transformers have long been available, the use of an associated cooling unit arranged above ground in the range of buried-type transformers announced by the Hackbridge and Hewittic Electric Company Limited, of Walton-on-Thames, Surrey, makes it possible to produce these units in much larger capacities than have hitherto been available.

The main feature of this equipment is the use of a standard oil-immersed core and coil assembly to give the advantages of very high reliability and economy. The transformer is of 500-kVA capacity, and has a voltage ratio of 11,000/433. Tappings are provided at $\pm 2\frac{1}{2}$ and 5% to a link board, access to which is gained through a handhole in the lid. The equipment simply consists of the transformer assembly in its tank, fitted with horizon-



Photograph by permission of F. Perkins Ltd.

One side of a Perkins flywheel machined in 2·64 minutes

This VERTICALAUTO NO. 10 (six-spindle model) is in the flywheel section of F. Perkins Ltd., Peterborough. It maintains a bore tolerance of ·0007″, and crankshaft register and starter ring diameters are held within ·002″ and ·0015″ respectively. There are nine tooling positions and the six 16″ hydraulically operated chucks are driven by a 60 h.p. main motor. Eight- and twelve-spindle machines are also available.

Ryder VERTICALAUTO

Thomas Ryder & Son Ltd., Machine Tool Makers, Turner Bridge Works, Bolton, England.
Makers also of single spindle Rydermatics and piston ring lathes.
STAND IH13 European Machine Tool Exhibition in Paris

tal incoming and outgoing cable boxes, and a cooling radiator, including a built-in conservator enclosed in a sheet-steel case mounted immediately above.

The transformer is buried directly in the ground on a concrete raft, whilst the radiator is mounted on a frame located on the transformer tank, so that the bottom of the case is flush with ground level. The outlet pipe from the radiator incorporates a stand-pipe to enable the oil to be circulated or the tank emptied. The tank is made from heavy-gauge steel, and all structural parts buried are protected by an application of flame-sprayed zinc covered by a coating of bitumen. The radiator is a sectional type of normal design, the case for which is arranged with cooling louvres on both sides, so as to give adequate ventilation. A lockable inspection door is included to provide access to the oil-level gauge and thermometer on the conservator cover. The whole assembly is neat and compact, its height being only 54 in., so that it is well below the eye-level of an average adult.

The development of this transformer opens up opportunities in districts where difficulty is experienced in obtaining adequate substation sites in congested areas. Installation can be effected at a kerb edge, fence line, or in any available location.

Units of smaller and larger capacity can be supplied, the height of the radiator being constant and the length adjusted according to the rating. If desired, the transformer can be arranged in a shallow brick-lined cavity with the transformer buried up to its neck, so that cable boxes and adjusting tappings can be conveniently reached. In addition, the radiator can be mounted separately and offset from the transformer within certain limits, if the site makes this desirable.

Eye-Movement Recording System

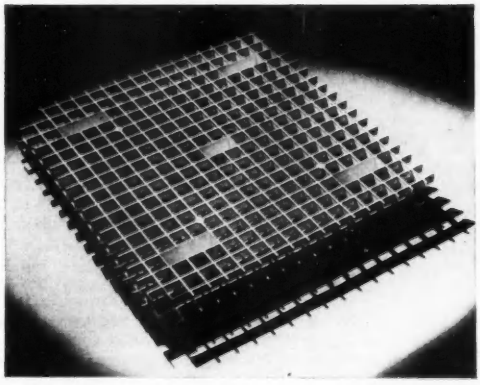
Electro-oculographic equipment for recording movements of the eyes, based on the differential changes in the standing d.c. potentials existing at the skin near the eyes and related to their angular deflection relative to the head, is not altogether new and has proved of great value in studies of eye response, reading ability, and particularly in the medical diagnosis of impairments to the inner ear.

The latest eye-movement recording system is that announced by Claude Lyons Ltd., of Hoddesdon, Herts. This system, designated type AS-1, comprises a very-high-gain, balanced, low-frequency amplifier, with associated power supplies, designed to operate a high-speed pen recorder and producing a continuous chart recording of eye movements. The instrument, which is extremely sensitive, utilizes a specially developed electrode system which does not require abrasion or puncturing of the skin, the cup-shaped silver electrodes being fixed to the skin by cellulose tape and allowing the subject complete freedom of movement and absence of any pain or discomfort, thereby ensuring full co-operation.

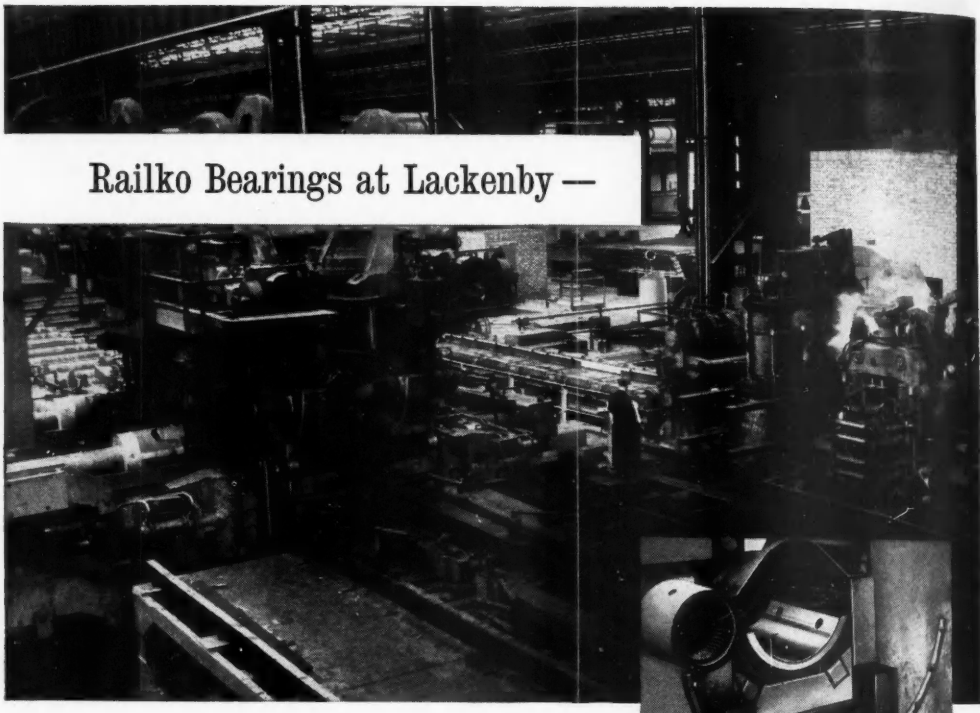
The equipment is housed in two cabinets which are interconnected by plug-in cables, the larger of the two cabinets containing the stabilized anode and heater power supplies, and the smaller cabinet the actual amplifier. The amplifier is fitted with preset gain and balance controls, and is calibrated by adjusting the controls to produce a given pen deflection when the amplifier input is switched to an internally supplied 100-microvolt reference signal. By virtue of its high gain, high input impedance, and low noise, the amplifying system can, quite apart from its use in recording eye movements, be used in a wide range of general physiological and technical applications, and, in fact, can be employed in conjunction with a suitable transducer and pen recorder for recording any function that can be presented as an electrical signal in the range between 0·02 and 50 cps.

New Plastic Packing for Cooling Towers

Head Wrightson Process Ltd., a subsidiary of Head Wrightson & Co. Ltd., of London, S.W.1, are providing for the Shell Petrochemicals site at Carrington, Manchester, two large " Counterflo " induced-draught cooling towers incorporating the new plastic " Poly-Grid " packing, which can be made either from high-density polyethylene or high-impact polystyrene, both of which are resistant to chemical attack and decay. Polystyrene is the less expensive material, but high-density polyethylene is the better material in certain circumstances.



The " Poly-Grid " packing is moulded in grids of 3 × 3 ft, with 2-in. sections having ⅜-in. " splash-strips " along the top of each rib and a 2-in. spacing between the decks by means of five tapered supports. Many tens of thousands of high-density polyethylene grids are required for each of these particular cooling towers, and each grid weighs about 4 lb. This packing offers the practical advantages of the splash-type packing with high operating efficiencies, and is suitable not only for use in new installations, but also for replacement of some or all of the wooden packing in existing cooling towers of all types. With this material it is possible to increase the cooling capacity of a tower already installed by providing material which does not suffer from the deterioration problems of certain thin timber laths. It can, of course, also be used in natural-draught towers.



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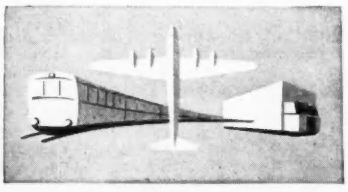

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ADDITIONAL ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

Process Welding of Nodular- and Grey-Iron Castings.
By B. Townshend and E. O. Porter. (From *Welding Journal. U.S.A.*, Vol. 38, No. 8, August 1959, pp. 329s–334s, 9 illustrations)

The ability to repair-weld nodular or grey cast iron successfully is a most important consideration to the manufacturer who is involved in the production and repair of these materials which possess good fluidity and castability, are easily machined, and are relatively inexpensive. Unfortunately, castings are not always perfect, and occasionally minor design and machining problems arise which have to be corrected. The overall cost of these castings to the consumer may be considerably reduced if satisfactory welding procedures are known and used

Many excellent articles have been written concerning the weldability of cast-iron materials. In general, however, preheats over 1000°F and involved procedures have been recommended which present difficulties to the production welder when large parts are involved. During the investigation described in this paper, particular emphasis was therefore placed on the determination of practicable procedures for welding restrained cast-iron parts.

A special, previously developed test-block was used to evaluate welding procedures. As a result of these tests, it was determined that sound welds can be produced in restrained joints of nodular cast iron or grey cast iron using the shielded metal-arc process with commercially available 55%Ni/45%Fe electrodes and a preheat temperature of 600°F. A buttering technique, i.e., depositing a pass of weld metal on the faces of a weld joint, followed by an intermediate heat treatment, was found to result in weld joints comparable in strength with that of the base material.

The most satisfactory technique found for producing welds with a minimum of porosity was one which employed a stringer-bead technique, using an arc length of about $\frac{3}{16}$ in., a minimum amount of weld penetration being desirable to obtain porosity-free-welds.

Kinetic Vibrations in Anti-Friction Bearings.
By B. Szöke. (From *Acta Technica Academiae Scientarum Hungaricae, Hungary*, Vol. 25, Nos. 1–2, 1959, pp. 3–24, 7 illustrations)

Causes of vibration in anti-friction bearings generally include careless mounting and manufacturing defects in the housing bore, the shaft, or the bearing itself. At constant load, vibration may also occur as a result of the elastic deformation of the raceways, even when no mounting or manufacturing defects are present.

The question arises as to whether vibrations may occur in anti-friction bearings when none of the causes hitherto known is operative, i.e., when raceways and rolling elements are considered as true circles and without deformation. The author has already pointed out on a previous occasion that, in certain circumstances, vibrations of a special type may occur in such bearings, even when they are assumed to be perfectly rigid and theoretically correct, and it is the object of the present paper to treat these considerations in greater detail.

It is known that, for safety of operation without undue heating, in radial anti-friction bearings there is a so-called radial clearance between the outer enveloping circle of the rolling elements and the outer raceway. It is shown that this fact itself is enough to generate vibrations, of a special form, called kinetic vibrations and that, owing to the action of the forces involved and the design of the bearing, they may arise even with races assumed to be rigid. This vibration pattern consists of a pair of curves, one of which is an arc of a circle; the other is obtained by tilting back the ball cage.

For a given bearing and a given load, the displacement angle of the starting point of vibration is a function of the rotational speed. At constant speed, the same spot on the race is invariably attained by the dynamic action, and this may lead to scaling. There exists a speed at which the final phase of the vibration takes place exactly after completion of a rotation equal to one pitch of the rolling elements. For each anti-friction bearing a factor can be computed which depends only on the design data of the bearing and which, multiplied by the square of the angular velocity of the cage, gives also external load per unit of rotating mass at which dynamic action due to kinetic vibrations is strongest. There also exists a rotational limit speed at which the vibration will cease, and a circling motion will be performed by the shaft centre.

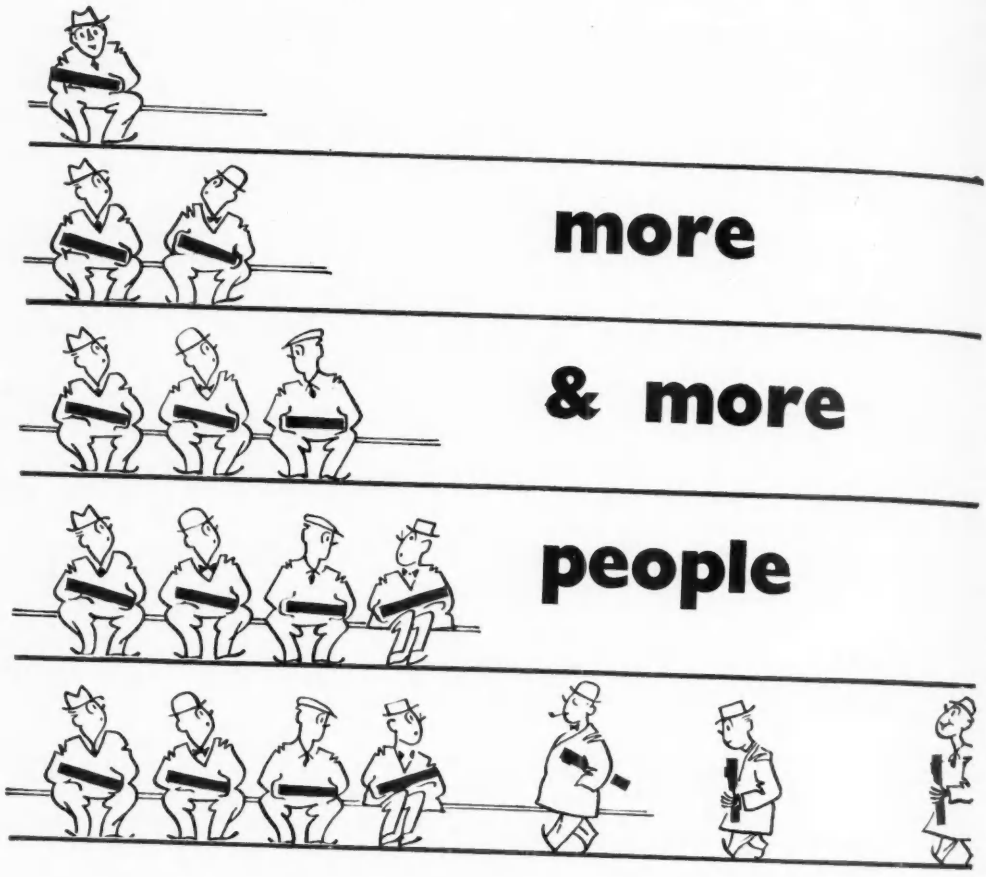
Failure Mechanisms in Glass-Fibre Reinforced Plastics.
By M. B. Desai and F. J. McGarry. (From *ASTM Bulletin, U.S.A.*, No. 239, July 1959, pp. 77–79, 4 illustrations)

It is known that there is an association between an internal cracking action of glass-fibre fabric-reinforced laminates and some of the curious tensile characteristics which these materials often exhibit. Most notable among the latter is the " knee ", or sharp modulus transition found with many laminates during their first loading to any appreciable stress level. This transition has been associated with an internal cracking by making water-absorption measurements on tension specimens stressed beyond such levels and comparing their weight gain after immersion with identically exposed specimens which had undergone no tensile stressing. The stressed or previously loaded specimens consistently demonstrated a significantly greater moisture absorption.

It was felt that such a simple yet sensitive technique would be useful in the study of fabric and resin actions and interactions in laminate behaviour and could be employed to improve the understanding of composite materials generally. For example, the effects of fabric weave, glass surface finish, resin properties, curing conditions and other parameters could be economically and informatively studied, both qualitatively and quantitatively, in this fashion, since an important criterion of any composite structural material is its retention of physical continuity under stressing. For these reasons, a somewhat more extensive study was undertaken and constitutes the subject of this paper.

The polyester, epoxy, phenolic, or other resins commonly used for laminates are notable for their comparatively low modulus, intermediate strength, and lack of ductility under tensile or shear stresses. Since glass filaments are much stronger and stiffer, and exhibit approximately the same ductility, initial impressions suggest that the two materials should function effectively when combined. This is true, unless the glass is woven into fabric, where the yarns are bent as they pass over and under each other.

In glass-fibre reinforced plastic laminates, internal cracking under tensile stressing takes place because of yarn crimp resulting from fabric weave and because of resin tensile and shear brittleness. Although this effect is recognized, it does not occur under compressive load-



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UM 33

ing, and cracking can be prevented by the use of non-crimp fabrics, if loaded in a principal direction, or by the use of more ductile resins. The technique of observation described provides a valuable tool for the study of the three-dimensional and interlaminar characteristics of such composite structures.

The Strain-Rate Sensitivity of Alpha-Uranium.
By C. J. MAIDEN. (From *Journal of the Mechanics and Physics of Solids, London*, Vol. 7, No. 2, pp, 106–113, 5 illustrations)

THE tests described in this paper were made in order to contribute to a better understanding of the pheonomenon of radiating growth in uranium, growth being the term used to describe the change of shape occurring in α-uranium under irradiation. Static and dynamic compression tests were carried out on two different batches of uranium, the static tests being effected on a 50-ton hydraulic compression machine and the dynamic tests on a special impact-testing machine. From these tests, static and dynamic stress-strain curves were obtained which indicate that α-uranium is slightly strain-rate-sensitive; thus, for example, the effect of increasing the strain rate from $2{\cdot}5 \times 10^{-3}$ per second to a value of several hundreds per second was to raise the stress at any strain rate less than about 4% by approximately 10%. Beyond 4% strain, strain-rate sensitivity was found, however, to decrease with increased deformation.

In order to determine the variation in dynamic strength of α-uranium with test temperature, as-cast specimens from the first batch of uranium were tested dynamically at temperatures of —41 and —84°C. The results obtained indicate that the rate of increase in strength with decreasing temperature is small, the effect of lowering the test temperature to —84°C being to raise the dynamic stress-strain curve corresponding to given test conditions by only about 5%. Also, to determine the effect of grain size on the dynamic strength of uranium, tests were made on the first batch of uranium in the beta-quenched state, and it was found that for identical test conditions, the derived dynamic stress-strain curve for the beta-quenched uranium was approximately 10% higher than for the as-cast material.

The second batch of uranium was also tested dynamically at 300°C in the rolled condition, and it was found that the dynamic compressive strength of the uranium in the direction of rolling was slightly greater than that of α-uranium in the as-cast state.

Aerodynamics of Wings and Bodies at Transonic Speeds.
By J. R. SPREITER. (From *Journal of the Aero/Space Sciences, U.S.A.*, Vol. 26, No. 8, 1959, pp. 465–485, 28 illustrations)

THIS paper presents a summary of the basic concepts and the principal results that have emerged from numerous experimental and theoretical investigations of transonic flow past thin wings and slender bodies. Emphasis is placed throughout on the correlation and evaluation of results provided by diverse methods for the approximate solution of the non-linear equations of the small-disturbance theory of transonic flow, and also on a critical examination of experimental results.

From the review of knowledge of the aerodynamic properties of wings and bodies at transonic speeds presented in this paper, two principal conclusions emerge. One is that substantial progress is being made in the development of methods for the approximate solution of the non-linear differential equations governing transonic flow. The other is that the results of calculations based on transonic-flow theory are consistently of almost surprising accuracy, considering both the small-perturbation approximation inherent in the fundamental equations of the theory and the novel nature of some of the procedures used to obtain approximate solutions of these equations. Much work remains to be done, however, in the application of these methods to an ever-increasing number of problems, and in the development of new methods for the analysis of such important facets of the transonic-flow problem as shock-wave boundary-layer interaction, which remain essentially unsolved at the present time.

While the development of a reliable theory for the prediction of the aerodynamic properties of wings and bodies at transonic speeds is a subject primarily of interest to aerodynamicists, it is hoped that the methods of approximation given, as well as some of the results for specific applications, may also be of interest to mathematicians concerned with the solution of non-linear partial differential equations. It should be clearly stated in this connection that the underlying reasons for the success of some of these methods remain only incompletely understood from a mathematical point of view. On the other hand, the demonstrated ability of these methods to reproduce closely the results of exact, but far more complicated, solutions and of experiments should be sufficient to warrant further mathematical study.

Significance of the Coefficient of Performance of Heat Pumps.
By C. W. BARY. (From *Applications and Industry (A.I.E.E.), U.S.A.*, No. 42, May 1959, pp. 90–94, 3 illustrations)

THE coefficient of performance of a refrigerating system is defined as the ratio of the heat absorbed at low temperature to the heat equivalent of work done. For an electric heat pump, operating on the heating cycle, it may be stated as the ratio of the total useful heat output (heat absorbed at low temperature plus the heat equivalent of work done) to the equivalent heat of electrical energy input. The object of this paper is to set forth the results of research on the load aspects and economic aspects of three residential heat-pump systems which employ supplementary heat sources, and to show a relative comparison of the economics of the utility's cost of service supply over a wide range of annual coefficients of performance.

From the analysis made in this paper on the basis of long-range and short-range considerations, the following conclusions are drawn:—

(1) Of all the systems considered, the heat pump with supplementary heat storage provides the lowest cost-to-serve level, and, at an annual coefficient of performance of around 3, approaches the reference band of competitive operating costs.

(2) Heat-pump systems with supplementary resistors produce acceptable cost-to-serve levels at higher coefficients of performance than 3, provided that they are sized for, and operate under, a fixed setting of indoor thermostats. When employing night set-back of such thermostats, their cost-to-serve levels become unacceptably high.

(3) Improvements in the annual coefficient of performance into the region of 3 and higher are essential for reducing the cost-to-serve relationship of heat-pump systems towards the reference band of competitive operating costs. However, for heat pumps which employ supplementary resistors, such improvements will be accompanied ultimately by higher cost-to-serve rates per kilowatt-hour than those existing under the lower coefficients of performance.

(4) The cost-to-serve levels of any of the resistance-type systems described fall far short of meeting the reference band of competitive operating costs, and their permissible saturation limits become insignificantly low under short-range considerations as a possible seasonal valley-filling load.

Thus, if an all-electric home is to become a mass-market reality, there must be further intensification in research and development of the heat pump for substantial improvement in its annual coefficient of performance and the adoption of some form of supplementary heat storage, which is dependent upon a successful development of heat-storage means.

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Fig. 1609

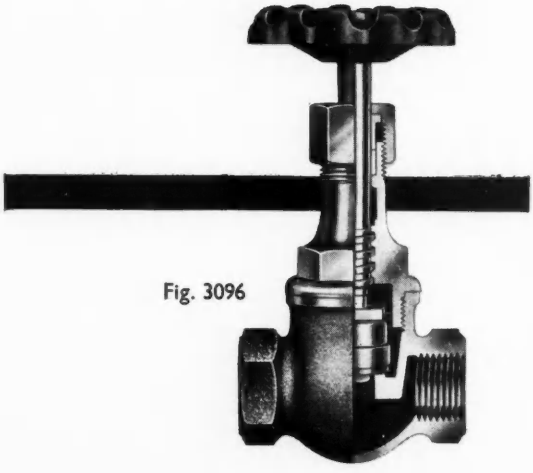

Fig. 3096

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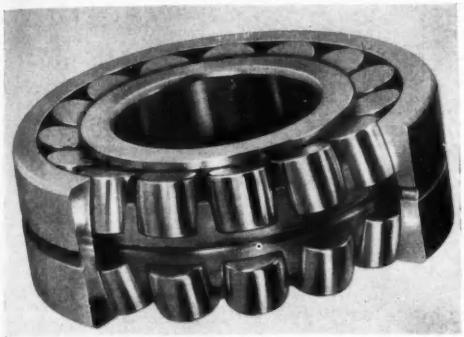
HIGH-CAPACITY SPHERICAL ROLLER BEARINGS

By incorporating such features as precision-machined centrifugally cast bronze retainers, high and heavy inner-race shoulders, and the highest possible number of convex rollers of maximum diameter, the new range of spherical roller bearings announced by the Link-Belt Company, of Chicago, Illinois, is believed to have the highest capacity of any spherical roller bearings at present available. Other features of these new bearings include trouble-free operation at high speeds, low operating temperatures, low noise level, efficient operation under the most severe conditions, and centre-groove lubrication.



In these bearings, which are being produced initially in bore sizes from 1·5748 to 11·0236 in., with dynamic ratings up to 288,000 lb, the centrifugally cast bronze retainers are accurately machined to extremely close tolerances, thereby ensuring smooth bearing performance, even under extreme speed and load conditions. Furthermore, the use of centrifugal casting produces retainers of such density and toughness that they offer maximum bearing performance under the most severe conditions of high eccentricity. Moreover, the use of higher and heavier inner-race shoulders makes it possible to assemble or remove bearings from the shafts with ease, using conventional shop equipment.

BEND TEST FOR HARDENED TOOL STEELS

The problem of testing fully hardened tool steels with hardnesses of more than 800 VPN is a difficult one, owing to the comparatively low ductility of these materials. Thus, conventional impact, torsion, torsion-impact, and repeated-blow tests have all been tried from time to time and, although each of these tests is of value for certain purposes, none has been completely satisfactory.

The Metallurgy Division of The British Iron and Steel Research Association (BISRA), of London, W.1, has for some time been carrying out research in connection with the testing of hardened tool steels, and has concentrated mainly on developing a bend test for assessing their toughness, which may be regarded as representing a combination of strength and ductility. In this connection, it has been found possible to use conventional tensile tests, but the conditions required are exacting, and great care is needed to carry them out. On the other hand, bend tests provide comprehensive information with a minimum of effort in making testpieces.

The method developed by BISRA uses a specimen 3 in. long, 0·2 in. wide, and 0·1 in. thick, the load being applied at four points and measured by a strain-gauge. The extension of the specimen is measured in such a way that it is easy to calculate the radius of curvature of the testpiece, and the design of the apparatus makes it possible to immerse the specimen in a liquid bath during the test, so that it can be heated without affecting the load of extension measurements. A mechanized version of this apparatus is being designed; in addition, a hand-operated version, which can be attached to a Hounsfield tensometer for carrying out tests at room temperature, has been developed.

The BISRA test method makes use of an improved method of calculating results, inasmuch as it eliminates the previously used unsatisfactory " classical " theory of bending, which gives results of comparative value only. The new method incorporates a correction for plastic bending, making it possible to plot a more accurate stress-strain curve. Values of mechanical strength can now be obtained that are within 2 or 3% of those given by conventional tensile tests.

It is stated that this bend test offers a useful method of comparing the toughness of tool steels, but is not suitable for assessing their cutting properties, which depend on other properties besides toughness, e.g., wear resistance.

LABORATORY ROTARY-DRUM CRYSTALLIZER

Incorporating all the essential features of their full-scale rotary-drum crystallizers and particularly suitable for handling metallic salts, such as sulphate of copper and nickel, the new laboratory rotary-drum crystallizer announced by the Kestner Evaporator & Engineering Co. Limited, of London, S.W.1, is completely self-contained and is designed for continuous operation.

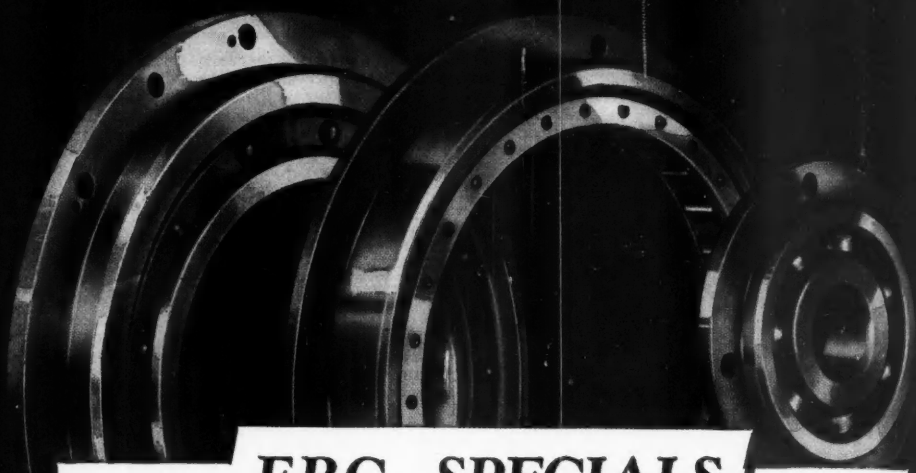
When warm saturated liquor is fed into one end of the inclined drum, it flows slowly to the other end, forming a thin film of liquor on the inside of the drum, owing to the latter's rotation. Cooling water is supplied from a distributor and covers the outside of the drum in a thin film, thus rapidly cooling the liquor film and causing crystals to be thrown out. The crystals and mother liquor flow continuously from the outlet end of the drum, when they can be filtered or centrifuged, as required. To keep the inside surface of the drum free from crystal build-up a special scraper chain is provided.

Great care has been taken in the design of this model to provide maximum flexibility under operating conditions. Thus, for example, drum speed is infinitely variable between 1 and 2 rpm, and alternative sprockets are provided to give a maximum speed of 20 rpm and a minimum speed of 2 rpm. In addition, the angle of inclination of the drum is infinitely variable from 0 to 5 deg. from the horizontal. The drum, which is about 90 in. in length and has a total cooling surface of 18 sq. ft, is made of stainless steel. The scraper chain is also made of stainless steel, and its position and tension are easily adjusted over a wide range to suit individual requirements. Alternative types of scrapers are also available.

HARD-HARNESS WIRING SYSTEM FOR AIRCRAFT

Although fundamentally designed to eliminate many problems in connection with electrical equipment in aircraft and missiles, a new hard-harness wiring system developed by Chance Vought Aircraft, Inc., of Dallas, Texas, is also expected to have applications in computers and other high-density electronic equipment, as well as in the wiring of buildings, ships, large machines, and even automobiles.

In the new system, bundles of insulated wires are completely encased in a tough, rigid, and compact cover of resin-impregnated fibre-glass. This stick-like, hard-



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coated wiring harness can be moulded into virtually any shape and can be formed to follow structural contours inside an aircraft or can take the form of an aerodynamic fairing for use outside an aircraft, missile, etc. The system is expected to solve several of the principal problems arising in connection with wiring, such as broken wires, chafing, and crowded installations. The fibre-glass covering is tough, heat- and abrasion-resistant, and resists accidental damage, reducing maintenance to a minimum, while its weight is considerably less than that of conventional harnesses. Furthermore, it occupies markedly less space than a conventional harness of comparable capacity. Thus, for instance, a conventional harness consisting of 360 wires of a particular gauge may form a bundle which is $2\frac{5}{8}$ in. in diameter or, if divided into six smaller bundles, a package which measures $3\frac{1}{4} \times 2\frac{1}{4}$ in. By contrast, the same number of wires of the same gauge can be carried in a moulded-harness section occupying only $1\frac{1}{8} \times 1\frac{5}{8}$ in. This is clearly demonstrated in the illustration, which shows (left) a section of conventional aircraft wiring harness, and (right) a section of the new harness carrying approximately the same number of wires of the same gauge. Other advantages are that the moulded harness can carry higher voltages, can withstand much higher temperatures and electrical overloads, and can tolerate vibration far better than conventionally harnessed wires.

The moulded harness can be designed into an aircraft much as a structural member, and its location can be predicted to within a few hundredths of an inch—an accuracy impossible with the loose-wire harness normally "snaked" through the interior of the aircraft. Should replacement of a harness section be necessary, a true, made-to-fit spare can be supplied, junction-boxes being strategically located to facilitate replacement. The hard harness, the fabrication of which requires relatively simple tooling, includes the provision of extra wires for the possible installation of additional equipment or to serve as spares, eliminating the need for splicing or running new wires alongside the bundle when changes in an electrical or electronic system are contemplated. Where a group of wires divides off from the main bundle, the "break-out" area is covered with a flexible section of tough plastic tubing.

MULTI-BLADE SCRAPER FOR CONVEYOR BELTS

Believed to be the most effective method of conveyor-belt scraping yet developed, the new multi-blade scrapers announced by Richard Sutcliffe Ltd., of Horbury, Wakefield, can readily be fitted to any type of belt-conveyor framework and have none of the disadvantages associated with conventional counterweighted belt scrapers. Thus, unlike the latter, they quickly react to variations in the belt line, and the scraper edge is not subject to excessive wear in the centre, where the bulk of abrasive material adheres to the belt. Also, as distinct from single-blade scrapers, which soon become ineffective as a result of severe wear in the centre, the multi-blade device has each blade mounted on a separate spring-steel bar, allowing it to wear individually in accordance with the amount of work it performs. As a result, no part of the belt is left unscraped, and cleaning efficiency is very much higher than it is with any other known types of scraper.

The spring-steel bar supporting the blade at right-angles to the carrying surface of the belt runs parallel to the centre-line of the conveyor and is carried at its opposite end by a cross-shaft, which is mounted in brackets on the side frames and carried by a spring-loaded torsion bar. Consequently, initial pressure can be applied externally by this bar, while local pressure is maintained by the spring of the individual bars.

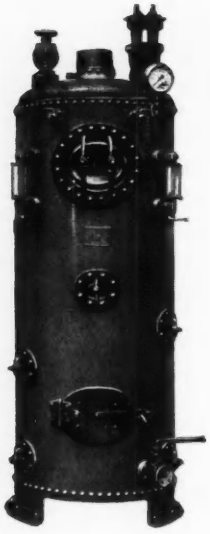
The blades are from 5 to 6 in. in width, and wear-resistant rubber, to a height of 2 in., is bonded onto each leading face. The rubber scraping edge and the steel blade wear down simultaneously, the wear rate of the rubber being far less than for scrapers with steel edges or squeegee rubber strips. The scraper is mounted so that the blades trail from the cross-shaft, preventing snagging by fasteners or projecting edges of torn belts. Inner and outer blades are interchangeable and are simple to remove.

Two sets of blades can be ranged across the width of the conveyor by mounting the spring-steel bars at a pitch slightly greater than the width of each blade, using alternate bars of different lengths. In this way, the belt is virtually scraped twice at each pass.

HIGH-PRECISION COMMERCIAL TEMPERATURE CONTROLLER

Believed to be the most accurate controller of its type at present available, the new Winston-United Steels precision temperature controller, type M.226, developed as the result of co-operation between United Steels, Ltd., of Rotherham, and Winston Electronics Ltd., of Shepperton, Middlesex, is capable of controlling continuously over periods of years temperatures to within limits of $\pm 0{\cdot}25$°C at 1000°C and above. As such, it has a wide field of applications, including its use in creep-testing, iron and steel foundries, and metallurgical research; in fact, it can be used wherever electrical thermometers operating up to 1200°C are needed and wherever a high degree of furnace control is essential.

Basically, the instrument comprises a platinum resistance thermometer which is formed into an a.c.-powered Wheatstone bridge, the preset arm of which consists of a 1000-ohm potentiometer graded in 4000 steps, each of 0·25°C. The out-of-balance voltage from the bridge is amplified by a two-stage amplifier giving a gain of about 2000, the degree of out of balance or temperature error being displayed by means of a "magic-eye" indicator with two degrees of sensitivity. The amplified output is also fed to a phase-sensitive bridge, which gives a positive or negative output according to whether the furnace temperature is lower or higher than the correct setting. This output is amplified ten times by the d.c. amplifier and is then applied to one section of the relay controlling the furnace relay. A time-interval generator provides switching cycles of 30 seconds to the other section of the relay control, which is so connected that the first section conducts, thus energizing the relay only when the control signal from the thermometer is more positive than the signal from the time-interval generator. When the furnace is at the correct temperature the relay is energized for half the time cycle, switching of the furnace relay being used to alter the furnace current between two values chosen to match the furnace characteristics.



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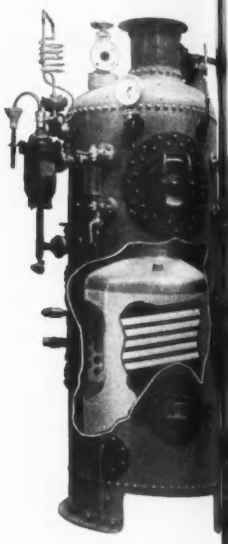

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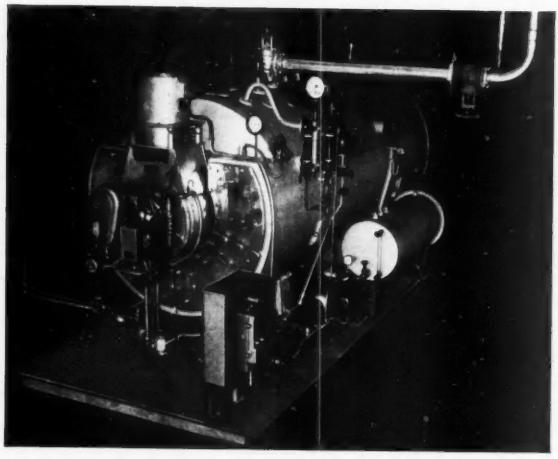

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NEWS OF THE MONTH

PERSONAL

A.E.I. Heavy Plant Division announce that **Mr. E. C. Berwick, B.Sc.(Eng.), M.I.E.E.,** has been appointed manager of large electrical machinery engineering (Rugby), **Mr. E. E. A. Grace, B.Sc.(Eng.), A.M.I.E.E.,** manager of medium electrical machine sales, **Mr. K. F. Raby, M.A.(Cantab.), A.M.I.E.E.,** manager of medium electrical machine engineering, and **Mr. W. H. Hunt,** superintendent of the medium electrical machines department.

Mr. H. J. Tucker has been appointed service manager of the Electric Resistance Furnace Co. Ltd.

Elliott Brothers (London) Limited, a subsidiary of Elliott-Automation, announce that **Mr. L. Bargit** has been appointed chairman and chief executive, **Dr. L. L. Ross** managing director, **Mr. E. O. Herzfeld** deputy managing director and controller, **Mr. G. C. Fairbanks** and **Cmdr. H. Pasley-Tyler, R.N.(Retd.)** assistant managing directors, and **Mr. L. C. Upsdell** a director and secretary of the company.

Mr. J. L. Foreman has been appointed sales manager of Nash and Thompson Limited, of Chessington, Surrey. **Mr. D. E. Morris** has been appointed sales office manager.

Sir Basil R. G. Tangye, M.I.Mech.E., has been elected chairman of The Production Engineering Research Council, in succession to **Sir Lionel Kearns. Sir William Stanier, F.R.S.,** has been re-elected president.

Mr. G. W. Bone, M.I.Mech.E., a director of Ruston and Hornsby, Ltd., has assumed responsibility for the company's engineering policy and for that of their associates, Davey, Paxman and Co., Ltd. **Mr. J. R. Bergne** has been appointed an assistant managing director of Ruston and Hornsby, Ltd.

The Taylor Woodrow Group announce that **Mr. L. V. Moere** has been appointed to the executive board of the group. **Mr. A. J. Hill** has relinquished his position as managing director of Taylor Woodrow Construction Ltd., but continues as chairman, while **Mr. T. Freakly** and **Mr. T. Reeves** have been appointed joint managing directors of the company. **Mr. R. E. Aldred** has been appointed managing director of Taylor Woodrow (Overseas) Ltd. and **Mr. J. Ballinger,** a director of Taylor Woodrow Construction Ltd., has been appointed to the executive board of Taylor Woodrow for a period of one year.

Westool Ltd. announce that they have appointed **Mr. M. H. Ley, A.M.I.E.E.,** as sales manager.

Monsanto Chemicals Limited announce that **Dr. N. B. Dyson** has been appointed manager, production planning and control, and has been succeeded as works manager by **Mr. G. V. Taylor. Mr. K. H. Handy** has been appointed works manager at Ruabon, Denbighshire, and **Dr. E. W. Bodycote** works manager at Fawley.

Mr. J. L. Ritchie, B.Sc.(Eng.), M.I.Mech.E., has been appointed sales director and an associate director of Holman Brothers Limited.

The English Electric Company Limited announce that **Mr. J. F. Herbert** has been appointed general manager, export sales, with special responsibilities for the interests of the company's Atomic Power Division. **Mr. S. E. Bolton** has been appointed assistant general manager, export sales, with special interest in the North American markets, and **Mr. S. W. J. Butler** manager of the new Overseas Factories Department.

Air Chief Marshal Sir Claude Bernard Raymond Pelly has been appointed member (Designate) for weapons of The United Kingdom Atomic Energy Authority.

Mr. R. P. Lister has been appointed home sales director of Coventry Climax Engines Limited.

Mr. G. B. Perry has been appointed managing director of Axia Fans Ltd., a member of the Hall-Thermotank group of companies. He has also been appointed a director of Vent-Axia Ltd. and will retain his seat on the board of Thermotank Ltd. **Mr. R. C. Adie** has been appointed general manager of the International Products Division and **Mr. H. J. Watson** of the Engineering Division of Thermotank Ltd.

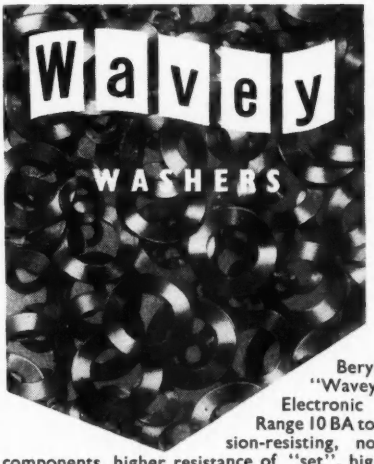
Mr. K. Fearnside has been appointed to the board of Smiths Aircraft Instruments Limited as director of research.

Mr. K. Allison has been appointed industrial-rubber products sales manager for the Goodyear Tyre & Rubber Company of India Private Ltd., of Calcutta.

Mr. I. D. Carter has been appointed commercial manager of Preformations Limited, a company of The Plessey Group.

OBITUARY

It is with deep regret that we announce the death on August 26, 1959, of Mr. E. Philip Jenkins, a director of Robert Jenkins & Company Limited.



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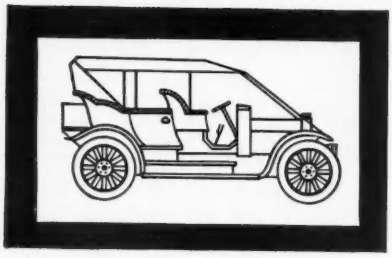

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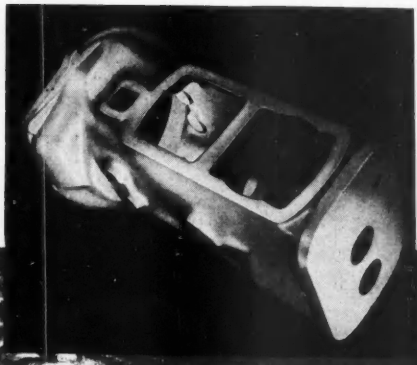
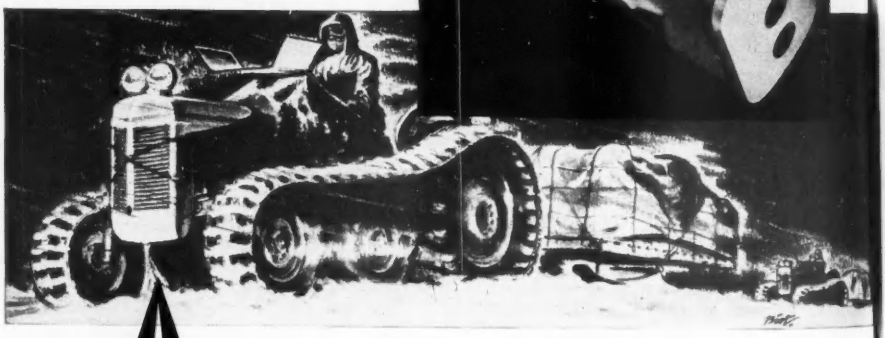
Transmission casing in magnesium alloy for Massey-Harris-Ferguson Tractors used in Sir Edmund Hillary's Antarctic Expedition. By courtesy of Massey-Harris-Ferguson Ltd.





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BUSINESS NOTES

An agreement has been signed between the **Société Nouvelle des Huiles Minerales,** of France, and **Rocol, Ltd.,** of Swillington, near Leeds, for the manufacture of Rocol molybdenized and other specialized industrial and motoring lubricants in France and for the distribution of these products throughout the European Common Market area. Meanwhile, **Rocol (Continental) A.G.,** of Horgen, Switzerland, will continue the sales of Rocol products in countries outside the European Common Market.

Nash & Thompson Ltd., of Chessington, Surrey, announce that they have concluded arrangements for the marketing of the G.K.N. micro-hardness tester, manufactured by **Associated Automation Ltd.,** of Dudden Hill Lane, London, N.W.10.

As a joint enterprise of **Interlas N.V.,** of Soesterberg, Holland, and of Mr. E. Courtney, who is well known for his past connections with British welding-positioner firms, a new company, **Interlas Limited,** has been formed to import and distribute welding plant and accessories throughout the United Kingdom. Mr. H. C. van Arum, managing director of Interlas N.V., has become chairman and Mr. E. Courtney managing director of the new company, whose offices, stores, and despatch departments will be opened in Ampthill, Bedfordshire. For the time being, business is conducted from their registered office, 232 Bromham Road, Bedford.

The formation of a new company, **Fenner Woodroffe & Co. Private Ltd.,** in Madras, has been announced by **J. H. Fenner & Co. Ltd.** and **Gordon Woodroffe & Co.** The new company will manufacture leather power-transmission belting for distribution through the depots and agents of **J. H. Fenner & Co. (Overseas) Ltd.** and **Henry F. Cockill & Sons Ltd.,** in India and certain markets in the East.

Cory Brothers & Company Limited, a member of the **Powell Duffryn Group,** have acquired the share capital of the **MacCleaster Chemical Company Limited.** The MacCleaster Company will continue to operate under their own name, and the present directors, Mr. N. R. MacCleaster and Mr. R. A. L. Thornton, will remain on the board. Additional directors appointed are Brigadier S. J. L. Hill, D.S.O., M.C., (chairman) and Mr. J. Wm. Davies, both also directors of Cory Brothers, and Mr. J. W. Franklin. The company's address is 8 Great Tower Street, London, E.C.3. (Tel: MANsion House 4555).

A new company, **Torvac Ltd.,** with a development works at Histon, has been formed to advise on design and manufacture of all types of special vacuum equipment for the use in the high, medium, and rough ranges, with special emphasis on metallurgical equipment and batch and continuous metallizing.

The small-tool and broach-manufacturing activities originally carried out by **B.S.A. Tools Ltd.,** have been transferred to two new companies, i.e., **B.S.A. Small Tools Limited,** of Montgomery Street, Sparkbrook, Birmingham 11, and **B.S.A. Broach Co. Limited,** of Studley Road, Redditch, Worcs. These two companies, together with B.S.A. Tools Ltd., will operate as separate and wholly owned subsidiaries of the **Birmingham Small Arms Co. Limited.** Management will continue to be carried on by the same executive personnel.

Formation of a new international company to serve the petroleum and chemical industries has been announced jointly by **Arthur G. McKee & Co.,** of Cleveland, U.S.A., and **Head Wrightson & Co. Ltd.,** of Thornaby-on-Tees. The new company, **McKee Head Wrightson Ltd.,** will have their headquarters in London, and will combine the experience of the two parent firms in the design and construction of petroleum refineries and chemical plants throughout the world, exclusive of the North American continent.

The **CVA Group** have opened executive offices at 79 Davies Street, London, W.1. (Tel: MAYfair 3051/2).

BTR Industries Ltd. announce that they have concluded an agreement with **Gewerkschaft Keramchemie,** of Siershan/Westerwald, Germany, to act as their U.K. representatives for the design, supply, and erection of chemical and corrosion-resisting plant and equipment. A joint design office is to be set up at the BTR head office at Herga House, Vincent Square, London, S.W.1, and the joint service will provide designs and schemes for plant protection.

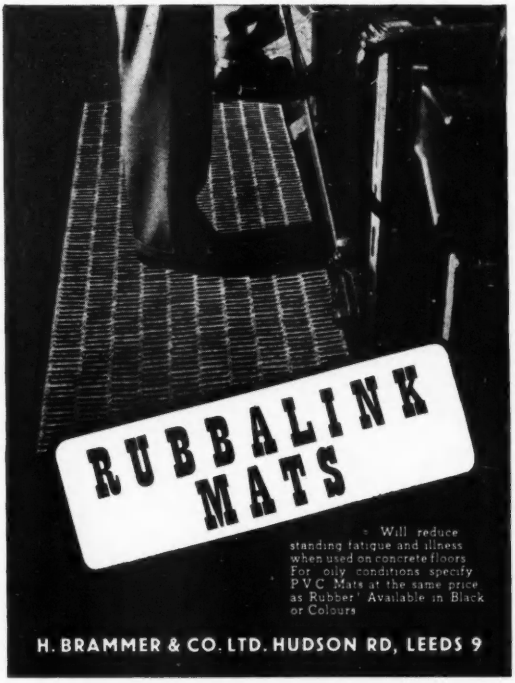
Charles H. Windschuegl Ltd., of Leadenhall Street, London, E.C.3, have been appointed sole U.K. agents for the mould-release agents manufactured by **Lange & Seidel,** of Nuremberg, Germany.

The production and administration of **Birflo Controls** have been transferred to **Laycock Engineering Ltd.,** of Victoria Works, Millhouses, Sheffield 8. (Tel: Sheffield 74411).

The entire offices and works of **Hardy Spicer Limited** and of **Birfield Engineering Limited** have been transferred to new premises situated at Chester Road, Erdington, Birmingham 24. (Tel: Erdington 2191).

Payne Products International Limited, of Green Lane, Hounslow, Middlesex, have been appointed sole selling agents in the U.K. and all overseas markets for all surface-finish equipment manufactured by **Armstrong (Leeds) Limited,** of Dewsbury Road, Leeds 11.

The Sykes Machine Tool Company Limited, of Staines, Middlesex, announce that they have been appointed agents for Great Britain for the range of facing, boring, and surfacing lathes, slotting machines, and various special-purpose lathes manufactured by Maschinenfabrik Ravensburg A.G., of Ravensburg, Württemberg, Germany.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A 16mm Colour Film with sound commentary, entitled 'Drop Forgings in Alloy Steels,' is available on request.

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CONTRACTS

A $410,000 contract for National dual-fuel engines driving Canadian-built alternators has been awarded to Orenda Industrial Limited, of Vancouver, by the Greater Vancouver Sewerage and Drainage District. They will be installed in the newly projected Iona Island sewage treatment plant to be constructed in the municipality of Richmond, Vancouver, B.C. The engines will be built by The National Gas and Oil Engine Company Limited at Ashton-under-Lyne, Lancashire, and will be shipped to their associate company, Orenda Industrial Limited, late in 1960. Both companies are members of the Hawker Siddeley Group.

Heenan & Froude Limited, of Worcester, are to supply eight dynamometers with a range of 60 to 250 bhp for use at Citroen's Paris factory. Other recent export orders for dynamometers include two special 700-bhp units for Société Turbomeca, gas turbine manufacturers, of Bordes, France, and four units for Automobile Products of India Ltd., of Bombay.

Following the completion of their new automatic hardening and tempering line, Caterpillar Tractor Co. Ltd. have placed further orders for furnaces with Electric Resistance Furnace Co., Ltd. The new orders, valued at nearly £50,000, cover the supply of both batch and continuous hardening furnaces and one continuous tempering furnace.

The National Coal Board, West Midlands Division, have placed an order with Head Wrightson Colliery Engineering Ltd. for a new coal-preparation plant at Wolstanton Colliery, Stoke-on-Trent. The plant, which will cost about £1,250,000, has been designed to handle run-of-mine coal at the rate of over 700 tons per hour.

Marco Conveyor & Engineering Co. Ltd., of London, in conjunction with the Constructional Engineering Co. Ltd., of Birmingham, have obtained an order from Yugoslavia for the supply of a complete mechanized foundry for the production of tractor engines. The whole of the equipment will be designed in Great Britain, but some parts of the steelwork will be fabricated in Yugoslavia, the equipment to be manufactured in this country being valued at £73,000.

In the face of keen competition from Germany, the U.S.A., and Japan, two British companies, Leyland Motors Ltd. and Metropolitan-Cammell-Weymann Ltd., have secured a £1,500,000 contract from Cuba for 200 diesel buses.

Overseas orders totalling almost £140,000 are announced by Fawcett Preston & Company, of Bromborough. Biggest of them is for nine pulp-steeping and two fibre-baling presses, to be incorporated in the rayon plant which Courtaulds Limited are building for Russia. Each of the steeping presses will weigh about 30 tons and will be 56 ft long. Pumping equipment will be supplied by Towler Brothers (Patents) Limited, of Rodley, near Leeds. The other orders comprise extrusion machinery for Pirelli, of Naples, Nordiske Kabel Fabrieken, of Copenhagen, and the Holland Insulated Wire & Cable Company, of Amsterdam.

M. J. Gleeson (Contractors) Ltd., of North Cheam, Surrey, have been awarded a £1,250,000 contract for the construction of the superstructure to Padiham "B" power station, near Burnley, Lancs. The scheme, to be carried out for the Central Electricity Generating Board Northern Project Group, includes the construction of a turbine house, a boiler house, and ancillary structures. Completion of the whole scheme is expected to be effected by December, 1962. The engineering consultants are C. S. Allott & Son, of Manchester and London, and the architects Cruickshank and Seward, F.R.I.B.A., of Manchester.

DEMONSTRATION OF NEW WELDING TECHNIQUES

A demonstration of new welding techniques was held at the Grafton Road, Croydon, factory of Rockweld Limited on August 27, 1959. Among the new developments introduced, special importance attaches to an automatic slag-welding machine, designated "Vertomatic", to be manufactured by Rockweld under licence from Czechoslovakia. This machine is claimed to achieve, compared with conventional welding methods, remarkable economy in the welding of heavy plates from 2-in. thickness upwards. Other processes demonstrated included the "Oxyarc" arc-cutting process, which utilizes a new type of consumable coated hollow electrode for cutting, piercing, and similar operations; the "Autopak" versatile all-purpose automatic submerged-arc welding process; and the "Comet" semi-automatic welding technique, in which the arc is struck between a special composite wire in a protective atmosphere of carbon dioxide gas. For all these processes special fluxes have been developed which provide good contour and appearance to the welding beads and ensure easy release of the gases created during welding.

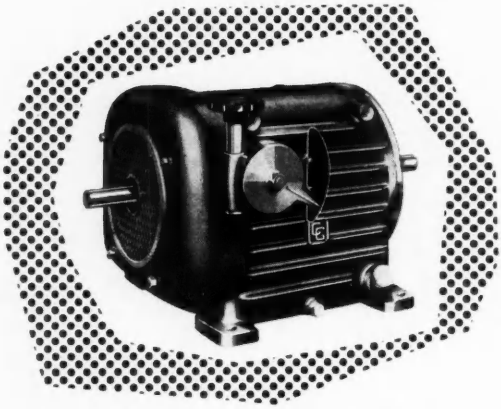
NEW FACTORY FOR PRESSURE VESSELS AND HEAT EXCHANGERS

Entirely new factory premises have been constructed for Steels Engineering Installations Ltd. at Crown Works, Sunderland, for the design and production of pressure vessels and heat exchangers for a wide range of industries. The new factory has several important and noteworthy characteristics, but of particular interest are the plate-rolling capacities. The pyramid plate-rolling machine installed has a very wide and useful range of capacities; thus, for instance, it can roll stainless-steel plate, $\frac{1}{2}$-in. thick and 10-ft wide, down to a diameter of 18 in., and 2×66 in. mild-steel plate to a minimum inside diameter of 30 in.

The production shops comprise three main bays, two of which run parallel, and a third which lies at right-angles and across the end of the other two. The larger of the two parallel bays, which measures 150×40 ft, is the plating shop, where plates for pressure vessels and heat exchangers are manipulated. In the adjacent bay, measuring 150×30 ft, tube bundles and all smaller parts for heat exchangers will be assembled or fabricated, and in the remaining bay, which is higher than the other two, the pressure vessels and heat-exchanger shells are welded and the various prefabricated sections brought together for assembly and testing.

A template shop, in front of the heat-exchanger shop, will provide wooden templates for such components as tube plates, dished-head blanks, pads, etc., and within this shop is a dark-room for loading and unloading X-ray film casettes and processing exposed films. At the side of this shop is the stress-relieving furnace, and above it the works offices.

Carter Hydraulic Variable Speed Gears



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A comprehensive enquiry questionnaire is available which, when completed, will enable our Technical Staff to offer suggestions for the most suitable and economical Carter Variable Speed Drives.
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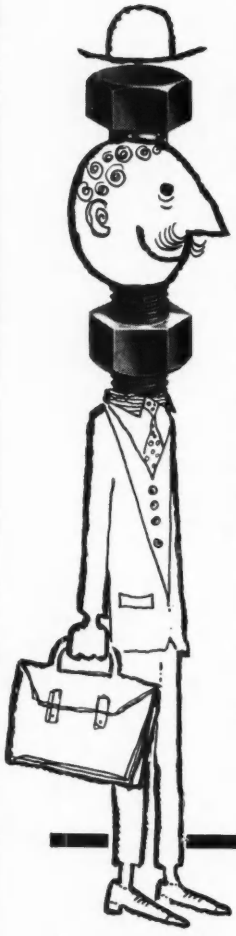

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NEW CONTINUOUS-CASTING DIVISION OF THE DISTINGTON ENGINEERING COMPANY

The Distington Engineering Company Limited, a subsidiary of The United Steel Companies Limited, have established a new continuous-casting division which will specialize in the design and manufacture of continuous-casting plants, both for ferrous and non-ferrous metals, on behalf of and under licence from Concast A.G., of Zürich, in which firm The United Steel Companies Limited have recently become shareholders. The continuous-casting division is currently engaged in the design of a wide-slab machine which will be capable of producing continuously cast slabs up to 50-in. wide and from 4- to 8-in. thick. The machine will be installed at the works of Société des Fonderies de Pont-a-Mousson, France.

LARGE-DIAMETER REINFORCED EPOXIDE PIPES FOR BATTERSEA POWER STATION

The reconstruction of drainage systems at Battersea generating station has involved the use of about 1000 feet of large-diameter reinforced epoxide pipes, making it the largest installation of this type of pipework in Britain. The epoxide pipe has replaced ceramic pipe in the system, which carries effluent from flue-gas washing plant, located in two of the four chimneys, to a treatment unit from which the effluent is eventually discharged into the Thames.

All the new pipes, manhole covers, and fittings were made from Bakelite epoxide resin, reinforced with glass fibre and Terylene, the latter giving added abrasion resistance to the inner surface of the pipes. The pipework was manufactured and installed by Mendip (Chemical Engineering) Ltd.

Two diameters of pipe are used in the installation, 18 in. and 15 in., and some are of elliptical cross-section to fit into narrow positions. The pipes have been produced in 10-ft sections, each section weighing about 90 lb and capable of being easily handled by one man. As the installation was carried out during the winter, often in temperatures below freezing point, the curing of the epoxide resin at the joints presented some difficulty. A method was devised of using blanket-type electric heaters over the outside of the joint, and large oil combustion heaters, in conjunction with fans, blew hot air through the pipes.

COMMEMORATION OF THE 250TH ANNIVERSARY OF COKE-SMELTING

In 1709, the Quaker ironmaster and founder, Abraham Darby, introduced a process which anticipated the Industrial Revolution later in the century and made economically and technically possible the rapid expansion of the iron industry which was such an essential part of the Revolution.

Darby was the first to achieve the successful smelting of ore with coke in the furnaces that he worked at Coalbrookdale, in Shropshire, and this achievement will be recognized by a three-day meeting on September 23 to 25, 1959, in Birmingham and Coalbrookdale, to commemorate the 250th anniversary of coke-smelting. This meeting has been organized by a national committee under the leadership of Sir Frederick Scopes, chairman of the Stanton Ironworks Co. Ltd., who is also chairman of the British Coking Industry Association.

The proceedings will open at the University of Birmingham on the evening of September 23 with an introductory lecture on the economic and social background of the iron industry in the 18th century by Professor T. S. Ashton. On September 24, four papers will be discussed, i.e., an account of the charcoal iron industry, by Mr. B. L. C. Johnson of the Geography Department at Birmingham University; the contribution of the Darby family to the development of ironmaking, by Dr. A. Ralstrick; a study of the events at Coalbrookdale in 1709, by Dr. A. Mott, of the British Coke Research Association; and a contribution on the history of ironfounding by Dr. J. G. Pearce, C.B.E., who recently retired from the office of Director of the British Cast Iron Research Association. Finally, on September 25, there will be a visit to Abraham Darby's furnace at Coalbrookdale, which has been restored by Allied Ironfounders Ltd., who have also established a museum nearby.

Those interested in attending all or part of this meeting can obtain fuller details from the Secretary, The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

NEW PLANT FOR TEXAS INSTRUMENTS LIMITED

Texas Instruments Limited, British associates of Texas Instruments Incorporated and Britain's largest manufacturers of silicon semiconductor devices such as transistors and rectifiers, announce that their new plant, due to be occupied in 1960, will have nearly treble the existing area and seven times the area first occupied by Texas Instruments Limited only 22 months ago. Plans are also in hand for two further stages, which will double this area.

The new building will have a manufacturing area, in the form of a hollow square, of 100,000 sq ft. At present, only 67,000 sq ft of this block is being constructed, leaving the mirror-image completing the square to be added at a later date. The manufacturing floor will be served from a basement, with mechanical services such as process gases, water, electric power, compressed air, etc. The delivery of services through the floor will enable the ceiling to be kept entirely clear of piping runs for these facilities, thereby avoiding dust-collecting areas. Access points to the manufacturing floor from the basement will be provided at close intervals to keep process piping within the production area to an absolute minimum.

In addition, 30,000 sq ft will be devoted to research, engineering, and administration, and this will be contained in a three-floor block which will be sited in the centre of the square. There will also be 17,000 sq ft for ancillary areas, providing entrance lobbies, stores facilities, a loading dock and housing for the air-conditioning plant, boilers, etc. Finally, 11,000 sq ft will be devoted to a cafeteria and kitchen which will be external to but adjoining the main building.

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NEW TECHNICAL BOOKS

Practical Ironmaking. By G. D. Elliot and J. A. Bond. 288 pp., 66 illustrations. Published by The United Steel Companies Limited, 17 Westbourne Road, Sheffield 10. Price 40/–.

Specifically directed towards students and to those actually engaged in some capacity in an ironworks, this excellently produced and illustrated book covers the operating principles of ironworks and deals with the theory of ironmaking in such a way that it can be used to assist day-by-day operation. Bearing in mind that the reader is assumed to have at least an elementary knowledge of the subject, plant descriptions have been kept to a minimum and no space is devoted to the raw materials of ironmaking.

As the authors point out in their introduction, the greater part of the book has been written around experience at one particular ironworks and, although the results may not be directly applicable to all other plants, and some experienced operators may disagree with much that has been written, it is believed that the underlying principles apply to all plants and practices. Certainly, there is a wealth of up-to-date information to be derived from this interesting volume on such subjects as the theory, design, cooling, and maintenance of blast-furnaces, the preparation of ores, operating procedures, refractories, slag, auxiliary plant, and sinter-plant control. In addition, there is a useful bibliography and a comprehensive index.

Cutting Fluids. Second edition, 1959. 60 pp., 27 illustrations. Published by the Esso Petroleum Company, Ltd., 36 Queen Anne's Gate, London, S.W.1. Price: 7/6.

Closely following the noteworthy advances made in machine-tool design and cutting-tool materials, corresponding advances have been made in cutting-fluid technology. This, of course is inevitable, as cutting fluids play an extremely important part in speeding up production by permitting increased rates of metal removal and by reducing, and often eliminating, problems associated with severe and hazardous machine operations. This excellent little book therefore admirably fulfils its purpose of giving engineers a better appreciation of the factors to be considered when choosing a cutting fluid, with a view to deciding on the best type to use for each different application.

Beautifully conceived and produced, this revised edition covers its subject concisely, but clearly and in sufficient detail to make it a useful reference work. Thus, chapters include pertinent information on the functions, applications, and use of cutting fluids, straight cutting oils, soluble oils, solution-type fluids, the selection of cutting fluids, cutting fluids for grinding, and even simple rules intended for the prevention of dermatitis, for which cutting fluids have very often been (sometimes unjustly) blamed.

Analytical Transients. By T. C. Gordon Wagner. 212 pp., 105 illustrations. Publishers: John Wiley & Sons, Inc., New York, and Chapman & Hall, Ltd., 37 Essex Street, London, W.C.2. Price: 70/–.

Written primarily as a textbook and based on the assumption that readers have an elementary knowledge of network analysis, this interesting volume represents a valuable means of acquiring the more advanced mathematical knowledge necessary for a greater understanding of network analysis, Fourier series, and the Laplace transformation.

Network analysis is first presented in a general manner, and then studied in detail. Much of the discussion in the book is devoted to the Laplace transformation, in order to provide a substantial idea of the subject as a whole, and to convey the sense of balance needed to perceive the limitations and applications of this calculus. The treatment of Fourier series and integrals establishes a logical basis for the Laplace transformation; a thorough consideration is given to the convergence of the series, the sampling theorems, and Gibbs phenomenon.

An especially significant chapter concerns the behaviour of linear systems of differential equations and the influence of discontinuous driving functions upon their solutions. In the section on stability, a general application of Sturm's and Routh's theorems is supplied. In addition Professor Wagner has included some applications of the Laplace transform to the solutions of the partial differential equations of transmission lines.

Reading German for Scientists. By Hans Eichner, B.A., Ph.D., and Hans Hein, B.A. 218 pages. Publishers: Chapman & Hall Ltd., 37 Essex Street, London, W.C.2. Price: 30/–.

Inasmuch as at least a reading knowledge of German is desirable for those who sooner or later have to consult German technical books or articles, this excellent book offers an interesting and commendable approach to a satisfactory command of the language by short-circuiting the methods usually employed in orthodox German grammars. To achieve this, the main emphasis of the book is placed on those aspects of grammar which must be known for the purpose of *reading* the language, while those needed merely to speak or write it correctly are touched on only lightly. Thus, the reading lessons, exercises, and examples are specially designed to introduce the student from the very beginning to the kind of vocabulary he is most likely to need in practice in connection with the basic exact sciences, especially physics and chemistry.

German is, of course, a complex and basically clumsy language, and a sufficient knowledge of its grammar and of the basic vocabulary of scientific texts is essential. This knowledge is imparted by the authors in a remarkably clear, concise, and practical way, most of the reading material being drawn from well-known textbooks and scientific journals. For convenience, the book has been divided into three distinct parts, the first (and longest) part being devoted to the grammar and syntax involved in reading German, and the other parts to actual readings in chemistry and in physics respectively. In addition, details of the Gothic alphabet, an English-German and a German-English vocabulary, and a comprehensive index are contained in an appendix. In short, this is an outstandingly good book of its type, and its authors merit the highest congratulations on the original treatment of their subject.

The Classical Theory of Fields. Second edition, 1959. By L. D. Landau and E. M. Lifshitz. 264 pp., 12 illustrations. Publishers: Addison-Wesley Publishing Company Inc., Reading, Mass., U.S.A., and Pergamon Press, Ltd., 4 & 5 Fitzroy Square, London, W.1. Price: 70/–.

Originally published in Russia under the title of *The Theory of Fields*, this translation into English by Morton Hammermesh is a thorough revision of the first edition, which appeared in 1941. Forming part of the authors' Course in Theoretical Physics, this valuable and instructive book is a systematic presentation of electromagnetic and gravitational fields for use in postgraduate courses.

The complete and logically connected theory of the electromagnetic field includes the special theory of relativity, which has been used as a basis for this presentation of the subject. As a starting point for the derivation of the basic relations, the authors use the variational principle, which enables the attainment of maximum generality, together with an essential simplicity of presentation. The last two chapters of the book are devoted to the theory of gravitational fields, i.e., the general theory of relativity. Here, the student is not assumed to have any previous knowledge of tensor analysis, which is worked out along with the development of the theory.

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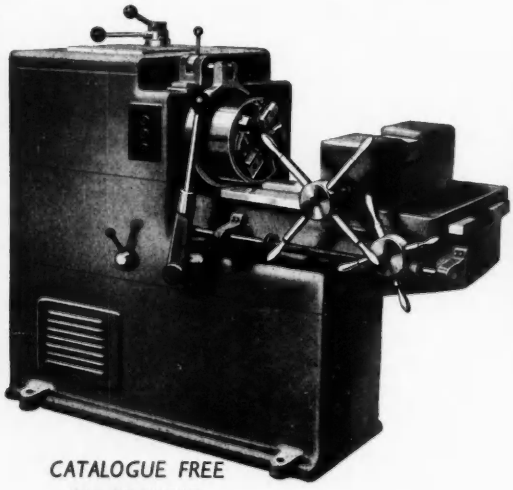

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